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ABSTRACT

This study investigated short term information retention of college biology students who used computer assisted instruction (CAI) with students who studied the same subject matter in printed form. An introductory computer program on photophosphorylation (the light reactions of photosynthesis) was written in Applesoft Basic for the Apple II microcomputer. From this, a printed version was made, almost verbatim. After using either the computer module or the written version in a laboratory environment, all students were tested using the same multiple-choice objective test. Results indicated that, when teaching photophosphorylation, CAI induced better learning in students than written materials, as measured by the test employed. The study is organized into these sections: (1) introduction (barriers to CAI, types of CAI, principles of learning, CAI compared to textbooks, past research); (2) methods/materials (development, formative/summative evaluation, data analysis); (3) results; (4) discussion; and (5) summary and conclusions. Appendices include complete photophosphorylation program listings, user's guide, written version, study guide, text (with correct answers), and related lecture material. (Author/JN)

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The Development and Evaluation
# of the Microcomputer Module Entitled Photophosphorylation

by

Catherine G. Leece

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The Development and Evaluation of the Microcomputer Module Entitled Photophosphorylation

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A REPORT

Submitted in partial fulfillment of the requirements
for the degree of

MASTER OF SCIENCE IN THE BIOLOGICAL SCIENCES

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INTRODUCTION

In the realm of education, computers may be used in a variety of ways. Basically they are used for information storage and retrieval, course management, test administration and computer-aided instruction (CAI). The use which has been considered the most controversial is CAI. CAI shall be defined here as a process by which written and visual information is presented in a logical sequence to a student by a computer (Frenzel, 1980).

Barriers to CAI

In the past it was predicted that computers would become a major part of the educational process (Luskin, 1972; Carnegie Commission, 1977). Current studies have shown, however, that the use of computers (especially for CAI) is increasing, but it has not yet become widely accepted (CONDUIT, 1978; Chambers and Sprecher, 1980). Basically there have been technological and educational barriers to the success of CAI in higher education. Namely, these barriers are affordability of hardware (computers and equipment), availability of good software, and lack of faculty interest and training. As a result, efforts are now being directed at eliminating these barriers.

In the past, hardware has been unaffordable for many institutions (CONDUIT, 1978), therefore it has not been acquired, much less utilized for CAI. High costs are mainly attributable to mainframe (time-share) computers. Researchers in the field now predict that educational computing is rapidly moving toward the use of inexpensive microcomputers (personal computers) (Bork, 1978; Chambers and Bork, 1980; Chambers and Sprecher, 1980). The cost of a computer, disk drive and monitor (video display) ranges between $1,000 - $2,000 today, and is rapidly declining. Bork (1981) predicts that the cost of computers will continue to decline, and has currently been dropping by 30% every year. He attributes this to increasing technological skill and mass production of components. Traditional instructional costs, such as that of books and teachers, have increased at a rate of 13% per year between 1977 and 1980 (Chambers and Sprecher, 1980). As a result of the lower cost for microcomputers, an increasing number of institutions may be apt to try CAI on an experimental basis.

Microcomputers are also advantageous in terms of size and speed. The microcomputer fits on a desk top and may be easily transported from office to classroom or laboratory. The user may choose the type of learning conditions desired. Microcomputers also eliminate time-sharing, down-time, passwords and slow graphics display all due to the number of users on mainframe systems. Many microcomputers have high resolution color monitors, text editing and some permit voice input and output. One disadvantage of microcomputers at this point is their small storage capacity, however better forms of mass storage are becomming available.

One of the problems associated with CAI software has been cost of development. According to Chambers and Sprecher (1980), about 50 - 500 hours of preparation time are needed for one hour of CAI user contact time on the computer. Lack of author sources is also limiting, because CAI authors must be knowledgeable in the subject matter, the principles of teaching, and computer programming, in order to produce educationally worthwhile material. This creates the necessity for software production by teams, thus increasing the investment of human labor into its production.

Software availability is also affected by lack of good material and lack of a good CAI language which can be transported (translated to another language or for other systems). Only a few sources of CAI material are available. In the early 1970's the universities of North Carolina, Oregon, Dartmouth, Iowa and Texas formed a consortium (CONDUIT) to acquire, evaluate and distribute instructional computing software (Chambers and Sprecher, 1980). CONDUIT is presently converting existing software for mainframes, to forms that may be used on microcomputers, as well as seeking new material. However, it is felt that the conversion of existing programs from other systems may not take full advantage of the unique capabilities of microcomputers (Spain, 1979). Alfred Bork is also producing both microcomputer and mainframe CAI material at the University of California at Irvine.

The final block to CAI success has been the attitude and background of educators. A prevailing attitude on many campuses has been intolerance of CAI, skepticism about its usefulness and hostility about its intrusion into the curriculum (Mosmann, 1980). Many CAI developers have attempted to replace traditional teaching methods (lecture etc.) with CAI. For this reason, Luehrmann (1978) went so far as to say that CAI will not be successful in schools because it threatens teachers. This may be true of some types of CAI, however, the human element in teaching has been found to play a major role in CAI success (Bunderson, 1981). Therefore the focus has been placed on the need for teachers to be trained in computer use, or at least in CAI implementation. Hopefully CAI can be developed to the point where administrator, faculty and student fears can be overcome. For, in addition to technological advance, only involvement and belief by educators can ensure that CAI is used to its full power (Bork, 1981).

Types of CAI

Of the limited CAI software that has been developed and implemented so far, there are two major categories: adjunct and primary (Chambers and Sprecher, 1980). Adjunct CAI is considered to be that which supplements the learning situation; the programs are used to support or illustrate concepts and generally take one-half hour to run. Primary CAI programs are usually lengthier and are developed for stand-alone use, or as a substitute for other modes of instruction.

Under these categories there are several formats or types of CAI programs. Those CAI types which are the most common are drill and practice, tests, games, tutorial and simulation. Drill and practice programs basically present problems and provide feedback. They are advantageous in that they can repeat problems, present problems based on previous answers and keep records. This type of drill may be tedious for a teacher, as the student's need for practice may excel the teacher's time and/or patience. The use of CAI for testing is limited mainly to adjunct use. Test questions are stored in the computer, to be randomly generated for each individual student. Tests can be graded and scores recorded and summarized for the teacher. CAI games are commonly used in elementary schools to introduce children to computers, and may improve students' attitudes toward the subject area. Tutorial programs present basic information, then lead the user to discoveries by means of strategic questions. This type of CAI is interactive and essentially consists of a dialog between the computer (specifically the programmer) and the learner. Finally, there are CAI simulations, which attempt to substitute for and/or supplement experiences and interactions with a given phenomenon.

Of the types of CAI discussed above, tutorials and simulations are the two types of CAI that come closest to real life learning experiences. CAI programs can provide a type of indirect experience, and experience is believed to enhance learning (Bork, 1980a). Also, many educators agree that the student/tutor relationship is the optimal teaching and learning situation (McKenzie et al., 1978; Tsai and Pohl, 1980; Bunderson, 1981). This is based on the fact that such situations are personalized for the individual, as are many CAI programs. Just as a tutor would do, CAI tutorials and simulations put the initiative in the hands of the student, and they are capable of giving reasonably flexible responses (McKenzie, et al., 1978).

Computer simulations may serve as a powerful tool in science education, especially in the laboratory. It may not always be practical or possible for students to interact with real phenomena in an attempt to learn. CAI simulations simplify an experience or phenomenon by means of a representative model, in order to make it accessible to the student's perceptions and understanding. If space, time, size or complexity are limiting, they can be altered in such a way that a simulation may be better for teaching purposes than the real thing (Dale, 1946). Simulations do not take the place of experience, but unlike most other modes of instructon besides experience, they may help create student insight (Abie, 1980; Bork, 1981; Petrakos, 1981).

Principles of Learning

In order to create educational media which are effective teaching instruments, educational technologists should follow a general learning theory upon which they can model their innovations. For the purpose of this report, the following quotation presented by Eisele (1980) serves as a good description of the processes which a student must go through to learn:

> The core problem in a science of instruction is the process by which the individual student learns. Instrumentation has potential for each step in the process. The learner is exposed to some material or stimuli; he must interact with that material in some active fashion as writing, talking, thinking or reasoning and the adequacy of the interaction must in some way be evaluated and reinforced.

What I would like to stress here are the ways in which CAI can affect and improve learning. With this in mind I will focus on what I feel to be the key words in the quotation above: interact, active and reinforce.

Most psychologists agree that active learning is superior to passive learning (Bork, 1981). That is, students do not learn merely by looking, they learn by becoming involved (Dean, 1946). CAI is capable of stimulating this type of active involvement which aids learning (McKenzie et al., 1978; Spain, 1979, Bork, 1980b). Dean (1946) believes that various instructional materials differ primarily in the degree of sensory experience they are able to provide. The more senses the student employs, the better may be the learning experience. These reasons form the foundation for the belief that CAI can be superior to printed material in establishing more effective learning.

CAI versus Textbooks

There are several properties of CAI which distinguish it from printed material in terms of facilitating active learning. In the reading of textbooks the process is commonly one of passively letting the textbook information "flow" into the individual (Bork, 1980a), that is, the material is not seriously thought about. As a tutor/student dialogue is created with CAI, the student can be induced to think.

CAI programmers attempt to actively involve students in learning by presenting frequent questions throughout CAI programs. The student can not pass by questions in CAI and (s)he is provided with immediate feedback. Psychologists agree that the best feedback occurs immediately after the event, to immediately reinforce learning and increase its effectiveness (Chambers and Sprecher, 1980; Bork, 1981).

The student's active involvement with CAI can also be reinforced by the immediate visual display of graphics; this is true mostly of microcomputers. This strategy has been termed interactive computer graphics (ICG) by McKenzie et al. (1978). As the student interacts with the computer terminal, graphical feedback is provided as a consequence of the interaction, such as when using CAI simulations. Many researchers believe that this visual immediacy of graphics enhances instruction, thus aiding the learning process (McKenzie et al., 1978; Heck et al., 1981). Books and CAI both allow information to be replicated accurately, but only CAI can replicate interactions accurately with true feedback (Bunderson, 1981).

Bork (1977) feels that visual presentation of material is often superior to verbal presentation. This may be related to the hypothesized learning strategy of mental imagery. If people generate mental images of the material they are learning, as suggested by Rigney and Munro (1981), graphics may aid them in establishing this mental image. The use of mental imagery is considered to have positive effects on the acquisition or processing of information. It is true that printed illustrations may also aid this strategy, but it is the animation and student manipulation offered by CAI which may make its illustrations superior in this respect. Also, CAI graphics may be used to cue the student on specific points by using strategic delays, or by flashing or moving things on the screen. There is no other medium which can offer this type of graphical display combined with user interaction. Finally, unlike printed material, CAI has no visual limitations. Information can be presented in a visually appealing manner, using different print styles, letter sizes, colors and spacing without additional cost.

Computer graphics are also believed to be highly motivational (Bork, 1980b, 1981). The topics which lend themselves to ICG are typically those which are difficult to teach (Spain, 1979). In addition, such topics are presumably difficult for students to comprehend. In such cases, Bork (1980b) sees graphics as providing the motivation needed to help students stay with the difficult parts. Not only are graphics considered to provide motivation, but in general, CAI has the capability of creating student interest, thus motivating students to learn (Bork, 1981; Bunderson, 1981).

Finally, CAI can facilitate learning at higher levels than can normally be accomplished with printed material. The recall of knowledge and the development of intellectual abilities and skills are considered cognitive functions (Ahmann and Glock, 1981). In the cognitive realm there are basically six hierarchical levels of performance (from simple to complex): knowledge, comprehension, application, analysis, synthesis and evaluation (Bloom, 1956). CAI is believed to have the ability to instill learning at the higher levels (Spain, 1979) by improving problem analysis, organization (Petrakos, 1981) and insight (Bork, 1980b), among other things.

The point being made here is not that CAI should replace printed media in education, but that CAI can be a valuable tool just as books have proven to be. The fact that print media usage builds on hundreds of years of development and traditions (Bunderson, 1981) creates the necessity for CAI developers to substantiate the fact that CAI can be the equal of books in terms of learning. It is a common belief that CAI alone is not a complete learning experience (Elder, 1975; McKenzie et al., 1978, Bork, 1981). In fact, no media is considered to offer a complete learning experience when used alone. This attitude was expressed long ago by Dean (1946) when he stated that "the more numerous and varied the media we employ, the richer and more secure will be the concepts we develop." This posture has also been taken more recently by Bork (1981). He feels that an environment truly responsive to students must have a variety of materials and techniques for learning. In light of this, any attempts made here to prove superiority of CAI over printed media, are done so only to establish the merit of CAI and clarify its potential role relative to other forms of media in education.

Past Research

Most research in the field, up to the present, has dealt with primary CAI and its comparison to the traditional teaching method of lecture. Very little work has been done concerning the comparison of books and CAI, especially adjunct CAI. The most significant projects involved in developing and evaluating CAI material for higher education are TICCIT (Time-shared Interactive Computer Controlled Television) and PLATO (Program Logic for Automatic Teaching Operations).

The TICCIT project was developed at Brigham Young University; CAI materials were developed based on concept and rule learning (Bunderson, 1981). TICCIT involved primary CAI English and mathematics courses that were taught at Phoenix and Alexandria Community Colleges. An evaluation of TICCIT was conducted by Donald Alderman of the Educational Testing Service (ETS); it contrasted the TICCIT courses with the same courses taught using regular classroom lectures. Chambers and Sprecher (1980) report that the mathematics course evaluation showed significant achievement effect of TICCIT over the regular classroom. However, fewer students completed the former than the latter course proportionally. Student attitudes towards TICCIT were less favorable than towards the regular lectures in the mathematics course, and did not differ in the English course. Achievement favored the TICCIT approach in English also, and the course completion rate was the same for both teaching methods. When reviewing these results it is important to note that the English TICCIT program included much more personal interaction between students and faculty than did the mathematics course (Chambers and Sprecher, 1980). Also, TICCIT allows limited use of video (Bork, 1981) which means reduced ICG.

The PLATO project was proposed by Donald Bitzer at the University of Illinois. It is a large mainframe educational system, however, since 1973 microcomputers have also been used (Bork, 1981). PLATO uses the CAI language, Tutor, which has full graphics capabilities. Donald Alderman of ETS also evaluated the use of PLATO in five fields in five community colleges as either a supplement to, or replacement of, regular classroom instruction. In no cases were PLATO programs used in lieu of an entire course. Chambers and Sprecher (1980) reported the ETS findings; basically, a significant increase in student achievement favored PLATO in mathematics, but not in accounting, biology, chemistry or English. Overall, students' attitudes toward PLATO-type materials did improve.

In a smaller scale study, Brown and Ellinger (1978) substantiated the idea that CAI is capable of inducing higher learning. An evaluation of a CAI spacial marketing package for Geology students was given to one group and traditional methods were used on another group. Posttests revealed a significant difference in learning between the two groups at the relationship and problem solving levels (CAI doing better), and no significant difference at the definitions level.

Most other studies based on the comparison of CAI and traditional methods have yielded somewhat consistent results in terms of learning differences (Chambers and Sprecher, 1980). Basically, the use of CAI either improved learning or showed no difference when compared to traditional methods (Paden et al., 1977; Deignan and Duncan, 1978; Magidson, 1978; Splittgerber, 1979). These studies, among others, also revealed that the use of CAI reduced learning time compared to traditional methods.

In spite of these conclusions, Herman (1977) points out a problem with most primary CAI studies - the drop out rate is usually much higher in primary CAI courses than in traditionally taught courses. Usually it is the poor achievers who drop out, thus raising the final class average. Herman suggests that this tendancy for drop-outs may be the result of student attitude. Many studies have shown that the use of CAI improved student attitudes towards the use of computers in the learning situation (Chambers and Sprecher, 1980). However, Herman has found evidence that some students find the basic CAI format unstimulating and confusing. Students have expressed their dislike for a controlled frame-by-frame approach. Some feel pressured and anxious because they usually can not retrace their steps. Contrary to the support given by most

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psychologists, Herman also reports that some students find that prompts and constant feedback interfere with their understanding of the material.

Finally, many people who implement primary CAI as an entire course do not seem to consider the problem of depersonalization. In a situation where CAI dominated a college freshman course for a year, at least 25% of the students expressed resentment against impersonal instruction (Herman, 1977). Thus some research does point to the need for sufficient human interaction when using primary CAI (Chambers and Sprecher, 1980; Bork, 1981; Bunderson, 1981), emphasizing again that CAI should not be used as the primary means of instruction.

The most conclusive study comparing CAI to printed material and other traditional methods of teaching was done by Tsai and Pohl (1980). The study was designed to determine significant differences in learning achievement and retention of university students exposed to an introductory level package on descriptive statistics. The study implemented the following treatment groups: lecture, programmed instruction (printed text), CAI, programmed instruction plus planned student/teacher contacts, and CAI plus planned student/teacher contacts. After eight class meetings, each group was given multiple choice and problem solving tests. Retention tests consisted of ten minute multiple choice quizzes given six weeks after the achievement test. The results showed that the CAI group did significantly better than the other groups on the multiple choice test, and the CAI-plus group did significantly better than all other groups on the problem solving test. There was no significant difference between groups for retention, whereas previous studies have indicated that CAI-taught students may not retain as much as those taught traditionally (Tsai and Pohl, 1980; Splittgerber, 1979).

Another project which has involved the development and evaluation of adjunct CAI materials is SUMIT (Single-concept User-adaptable Microcomputer-based Instructional Technique). SUMIT was developed at Michigan Technological University by James D. Spain and supported by a National Science Foundation grant. The objective of the SUMIT project was to develop, evaluate and disseminate 20 interactive graphics programs for use on Apple II microcomputers in general biology and ecology. Unlike any other attempt to produce marketable microcomputer CAI to date, the SUMIT approach encourages the integration of computer simulation into a course, especially biology laboratories (Spain, 1979). Programs utilize mathematical models, feedback, interactive graphics and many are programmed to facilitate modification by the user. A majority of the material developed by SUMIT has undergone evaluation in various biology courses, but the results have not yet been compiled or published. By administering pre- and posttests immediately before and after students run a program, the general finding has been that students show increased achievement in the subject area to which they were exposed (Soldan, 1982).

Problem Statement

In spite of the numerous studies which have been done to test the effectiveness of CAI, there is still a need for research. After reviewing the literature, Chambers and Sprecher (1980) concluded that well-designed, tightly controlled evaluative studies on the use of CAI are rare. It was their recommendation that the appropriate use of CAI materials in the learning situation should be studied and implemented.

Considering the forecast of increasing microcomputer popularity in education, it is important that more research focuses on the use of CAI on microcomputers. Due to the prevalence of mainframe CAI, very few studies have looked into using microcomputers in their evaluations. Also, since most evaluations have centered on primary CAI, it is important to develop and evaluate adjunct CAI materials. Since CAI is slowly being ruled out as the means of teaching entire courses, it is important to investigate its use as a supplement to traditional methods, especially in laboratories. I have not encountered any literature in which CAI was incorporated into laboratory work. Finally, any studies which may deal with adjunct CAI have not compared CAI learning to learning from printed text. In view of these deficiencies, I developed an adjunct microcomputer program for use in a general college biology laboratory course.

After carefully considering the existing software in biology and considering what topic would lend itself to CAI on the microcomputer, I chose to write an introductory program on photophosphorylation (the light reactions of photosynthesis) for the Apple II Plus microcomputer. I chose this topic to fill not only a need for microcomputer CAI, but to fill a need for biological programs specifically. CONDUIT, a leading software distributer, offered a total of eight biology CAI packages for microcomputers in a recent catalogue (CONDUIT, 1981). None of these dealt with photosynthesis. I have encountered one Apple II BASIC program by J&S Software (1980) which deals with photosynthesis; it is a drill and practice program made for review purposes. I chose photophosphorylation specifically, due to the need for CAI development in plant physiology, and because I felt it would lend itself to interactive computer graphics. I also believed that it could be easily incorporated into photosynthesis laboratory work. Finally, I felt that it was a topic which could employ interaction and many of the capabilities offered by an Apple II, thus it would serve to highlight any differences between CAI and printed material in those respects. Since the program was to be used as actual instructional material in a course, I also felt it was important to provide the students with a topic from which they could benefit; my experience indicates that the photophosphorylation pathway is often difficult for students to understand and learn.

In view of the above considerations, the purpose of the present study was to compare the short term information retention of students who used CAI, with those who had been exposed to the same subject matter in printed form.

METHODS AND MATERIALS

Development

The design and development of the microcomputer program entitled Photophosphorylation was largely based on styles and techniques which have been recommended or proven successful by others in the field. Since tutorial CAI is best suited to enhance concept learning and simulations are best suited for enhancing concept integration and higher learning (Bunderson, 1981), I chose to combine the two types into one program. Instructional simulations may either present information to a passive learner or interact with a participating learner (Fortner, 1979). I chose to implement the former type in this program; this was mandated by the length and complexity of the lesson. The program design and construction followed the approach outlined below, adapted from Spain (1979), and Agin and Simonsen (1982) in combination.

I. Program Design

  A. Specify learning objectives of subject area
  B. Specify appropriate level of abstraction for anticipated users
  C. Write preliminary guide containing necessary background information

II. Program Development

A. Write preliminary flow chart based on objectives and desired sequence of learning
B. Write initial program using open structure for later modification
C. Edit, add to, debug, document and modify program in preparation for trial use
D. Write User's Guide

Since the development of this program was done in conjunction with the SUMIT project, SUMIT guidelines were used in preparing the User's Guide. A User's Guide is essentially a student/teacher manual designed to explain and supplement a specific program. The basic guide format included an abstract, program prerequisites, learning objectives, background information, applications, exercises, program description/documentation, and references. The Photophosphorylation User's Guide is presented in Appendix C. The User's Guide was not used in the module* evaluation for two reasons: 1) users of both the written and computer modules would have had to use it to prevent bias, and much of it would not apply to the written material, and 2) past experience with SUMIT has shown very few students even glance at the User's Guide when it is available. (* I will use the term module to encompass both the program and the written version.)

Program content was based on information presented by Lehninger (1975) and Stryer (1981). Since these are advanced biochemistry texts, care was taken not to use information above the general biology level; Curtis and

Barnes' Invitation to Biology (1981) was used as a guideline in this respect. The program basically consists of four parts, an introduction, explanations of the non-cyclic and cyclic pathways and a simulation of the entire pathway. The explanation sections consist of a step-by-step analysis of the pathways at the molecular level. The student is led through the program in an ordered fashion and after each section (s)he is allowed to review any portion of the program, as well as watch the pathway simulation for an ample amount of time. The program took approximately 200 hours to develop, and it takes 30 - 45 minutes to run, depending on the study patterns of the individual. Agin and Simonsen (1982) consider this a desireable length for an adjunct CAI program. The diskette on which the program is stored can be found in Appendix A, and complete listings of all subprograms are presented in Appendix B.

The programming style that was utilized, was based on the anticipation of user needs and preferences. In order to motivate students to read the text portions of the module, two strategies recommended by Kehrberg (1979) were used: 1) text was broken up with questions, and 2) the amount of text on the screen at any one time was kept to a minimum. In addition, dialogue was kept informal, as suggested by Bork (1979, 1981). The screen display was put in the hands of the user to avoid frustration; pages are controlled by pressing the return key, not by timed pause loops.

Questions are not put in endless loops, but allow the user to go on after a maximum of two incorrect responses. Also, the user may not pass by questions without trying to answer them. Users are warned if there is to be a delay, for example when loading subprograms, so they do not feel as if something went wrong with the program. User confusion is also minimized by consistency in the nature of input required by the student (Kehrberg, 1979). All actions are initiated by pressing the return key, and all inputs have to be followed by pressing return before they are analyzed by the computer. Finally, when a particular action is to occur, the user's attention is drawn to it prior to the event. Fortner (1979) stressed the importance of briefing the student before a simulation so the student knows what to expect, thus aiding his/her understanding of the event. In essence, the majority of the programming tactics implemented, were used to incorporate effective teaching strategies into the CAI program.

The printed material, hereafter termed the written version, served as the traditional form of instructional media. The written version consisted of the same information contained in the program, almost verbatim, except that: 1) entire pages were filled with text as is commonly done in textbooks [illegible] 2) computer terminology was eliminated (e.g. "Press Return," etc.). When students encounter questions in the written version, they are referred to an appendix to check their answers. No reinforcement is given, just the correct answers and pertinent explanatory notes. CAI simulations are represented in the written version by printed flow diagrams, which are placed preceeding those sections which refer to them. A copy of the written version is presented in Appendix D.

In addition to the written version, a one page study guide was prepared for issuance to each student at the time of the evaluation (see Appendix E). The study guide consists of general instructions, motivation statements and 12 learning objectives to be achieved as a result of using the module. Motivation was mainly provided by announcing that the test score achieved by each student participating in the evaluation, could be used to replace the student's lowest quiz grade in the course. Bork (1981) and McKenzie et al. (1978) feel that for many students, grades influence their classroom performance and commonly serve as motivation. The learning objectives were based on the original objectives I set up when developing the program. I tried to touch as many levels of learning as possible with these objectives; unfortunately many of them were aimed at the knowledge level.

Formative Evaluation

The evaluation process began with a formative or "midstream" evaluation of the program and the test. This evaluation served to provide information on the effectiveness of the material at an intermediate point in development. Ideally a large group of students representative of the target population should have been used for this process (Brown and Ellinger, 1978). This was not possible due to lack of a test group. Therefore a small scale more intensive evaluation was performed. The program was initially reviewed by members of the SUMIT research team; Agin and Simonsen (1982) recognize this as an appropriate first approach to checking a program. Essentially, attempts were made to "bomb out" the program and detect programming errors. The second step was to get comments, criticisms and suggestions from as many professors and graduate students as possible, who were knowledgeable in photosynthesis. These people basically analyzed subject validity, ambiguity, readability etc.

Summative Evaluation

A class of 102 students enrolled in General Biology (BL 104) at Michigan Technological University participated in the summative evaluation. Class statistics (major curricula etc.) are presented in Appendix H. Students were exposed to a lecture on the topic of photophosphorylation, given by their regular lecture instructor, approximately 42 days before they used the module. A copy of the fundamental lecture is presented in Appendix G. At the time of the lecture, students were also required to read pages 110-122 and 287-292 of Curtis and Barnes' Invitation to Biology (1981); this material covered the leaf and photosynthesis. Two weeks before the summative evaluation, the students took a midterm examination in the course; at that time they were responsible for the photophosphorylation lecture and reading material. Based on this, it was assumed that a majority of the students had studied the topic material at some time prior to the summative evaluation.

Students had been exposed to the Apple II microcomputer and a series of SUMIT CAI programs in laboratory prior to the evaluation. All students were required to run a program introducing them to the Apple II computer, the first week of the course. All but one of the five lab sections was required to run a manditory CAI program in lab every other week. A schedule of the lab topics and CAI programs used in lab each week up through the evaluation are presented in Appendix I. Current and previously offered programs were made available in the lab at all times.

The tool used to perform the summative evaluation was the 20 item objective test developed from the learning objectives. Test items can be considered direct expressions or operational definitions of the learning objectives (Ahmann and Glock, 1981). The importance of each objective, in terms of the total lesson, was used to determine the number of test items related to each. The numbers of the test items which satisfy each objective, are presented in parentheses after each objective in Appendix E; an item may satisfy more than one objective. Objective test items were used to eliminate all subjectivity when determining the correctness of each answer. The test consisted of 18 multiple choice and 2 true/false items; it is presented in Appendix F. The construction of these items followed guidelines presented by Ahmann and Glock (1981) on pages 78 - 89. The length of the test was more or less arbitrarily determined, being long enough to provide statistically valid data and short enough so as not to take up too much lab time. Based on the method of construction and purpose of the test, I would consider it to be a norm-referenced achievement test. That is, it served to find each student's performance level in relation to the performance of others taking the test (Ahmann and Glock, 1981). Thus the test attempted to produce variability among test scores, so differences between the two groups of students could be accentuated and attributed to the educational media they used.

Test items were analyzed by a professor of biology and a professor of education. They were also analyzed by a colleague who had run the program; he reasoned through the test aloud, in my presence. This allowed me to recognize major problems with question wording and distracters (choices). I edited the necessary questions based on evaluation findings and verified the relationship between each of the items and the objectives on which each was based, to assure content validity as suggested by Ahmann and Glock (1981).

The summative evaluation took place over a two day period involving all five laboratory sections with approximately 20 people in each. The lab schedule is presented in Appendix H. Two of the labs were taught by myself, the other three were taught by two other graduate teaching assistants. Unfortunately, it could not be arranged for the lab work to correlate with the module lesson, in subject matter. Thus, the lab work dealt with ecology and soil testing. This lab is presented on pages 99-110 of Christianson and Krear's Laboratory Scripts for General Biology (1981).

The students received two brief lectures before starting the lab work or module. The first was an explanation of the lab work to be done, given by the regular instructor. This was followed by a set of instructions presented by myself to insure that the same thing was said to each group. The following points were stressed:

- You are participating in an experiment with carefully designed controls.
- It is important to the field of education and to my Master's work.
- Think of the module as an integrated part of your labwork.
- Do not bias the experiment with your personal feelings about which teaching method is better.
- Do not communicate with others in the lab or in other lab sections about the module or the test.

- Try to follow the instructions and do your best to learn the material.

I also presented two reasons for learning photophosphorylation during an ecology lab: 1) it would help prepare students for the photosynthesis lab two weeks later, and 2) photophosphorylation is commonly a difficult thing for students to comprehend, thus I thought a special module would help. According to Herman (1977), cues that the material is going to be a challenge, are more effective in stimulating learning than cues that the material is going to be easy. Study guides were distributed to each student; from these I read the instructions and stressed the use of the objectives as a learning guide to the material. The objectives were generally presented in the same order as they were covered in the module.

After the instructions, each student was told which group (s)he would participate in. Each lab section had been randomly divided into two groups, control (written version) and experimental (CAI), by means of an Apple II randomizing program written by Shaltz (1982). Each of these groups was randomly divided in half again; this determined who was to do the lab work before looking at the module and vice versa. In cases where extra or missing students caused a major group imbalance, a coin was tossed to rectify the situation. The random experimental design described above was used to eliminate possible bias between sections or individuals and eliminate congestion in the lab.

After I completed my instructions the students began their work. Seven microcomputers were set up in an area which was remote from the main lab. Written versions were passed out by the instructors and most students read these in the study carrells. The written versions had to be handed in before students could receive the test. The same test was used for all students. Also, the test was not timed and it was taken on an individual basis in the designated test area immediately after students finished their modules. Notes etc. were not allowed during the test; the test area was periodically "patrolled." Lab instructors handled problems the students had with the module or the lab work. Students recorded their test answers on IBM computer answer forms, which were then scored against a key by the M.T.U. Academic Computing Services.

Data Analysis

The data (test scores) were divided into four groups: Written version/Lab work first (WL), Computer version/Lab work first (CL), Written version/Module first (WM) and Computer version/Module first (CM). One score from each of the WL and CL groups was randomly thrown out to equalize all four groups resulting in 25 scores in each; this was not done to the item analyses data, discussed later. Bartlett's test for homogeneity of variances (Zar, 1980) was performed to determine if all samples came from the same population. To determine if each sample group came from a normally distributed population, D'Agostino's test for departure from normality (Zar, 1980) was used. These tests were followed by the use of a Model I 2X2 Factorial Analysis of Variance (ANOVA) with replication (Zar, 1980). ANOVA served to determine the effects of the instructional media on the scores, the effects of the order in which lab work was done and the interaction of these two factors. Consequently, Duncan's New Multiple Range Test (Duncan, 1955) was used to compare all four group means to detect differences.

To analyze the data at the test item level, a program entitled Item Analysis (Fehlberg and Flatham, 1969) was run on a UNIVAC 1110. Each student's answers were coded onto a general purpose punch card and cards were divided into two groups (computer and written). These group data were each separately incorporated into the analysis program and run through the computer, with an additional run using all data collectively. The program produced the following usable statistics: KR-20 Reliability Coefficient, item difficulty indices, item test score means, item z-score means, item biserial correlations and item reliability indices. These statistics are used to determine the strengths and flaws of each item, as well as to distinguish between the two treatment groups. The difficulty indices for each group were compared for each item, by means of a test of the equality of two proportions (Fruend et al., 1960). Items which revealed significant differences in difficulty were further analyzed at the distracter level to determine where the differences existed. From this, postulations of what caused specific learning differences between the two treatment groups were made.

RESULTS

The majority of conclusions made about the effectiveness of the CAI program versus the written version were based on the following statistics. ANOVA assumptions were satisfied first by using Bartlett's test for homogeneity of variances which yielded a calculated chi-square value of 1.207. The critical value at alpha = 0.05 and 3 degrees of freedom was 7.815. Thus the null hypothesis (all sample variances estimate the same population variance) was not rejected. D'Agostino's test for departure from normality resulted in acceptance of the null hypothesis (the sample came from a normal population) for all groups. The distribution of the data can be seen in histogram form for the whole class, computer (CAI) group and written version (W) group in Figures 1, 2 and 3 respectively. The means, variances and standard deviations of each group are also presented in these figures. A comparison of Figures 2 and 3 reveals that the CAI group had a larger mean (14.80) and smaller standard deviation (2.79) than the W group (mean = 12.16, s = 3.52).

Table I. Analysis of Variance summary table for Photophosphorylation test scores. Factor A is the type of media used (computer or written) and Factor B is the order of task completion (lab or module first).

Source of Variation	SS	DF	MS	F
Cells	277.92	3		
Media (A)	174.24	1	174.24	18.86**
Order (B)	51.84	1	51.84	5.61*
A X B	51.84	1	51.84	5.61*
Error	887.04	96	9.24	
Total	1164.96	99		

* significant at alpha = 0.05
** significant at alpha = 0.01

```
Freq.   0  0  0  1  0  3  1  6  7  4  6  8  4  5  4  1
8                                        +
7                               +        +
6                            +  +     +  +
5                            +  +     +  +     +
4                            +  +  +  +  +  +  +  +
3                      +     +  +  +  +  +  +  +  +
2                      +     +  +  +  +  +  +  +  +
1                +     +  +  +  +  +  +  +  +  +  +  +
---//---------------------------------------------------
        5  6  7  8  9  10 11 12 13 14 15 16 17 18 19 20
                          Test Score

     Mean = 14.80   Variance = 7.80   St. Dev. = 2.79
```

Figure 2. Frequency distribution of Photophosphorylation test scores for the computer group. + = 1 score, N = 50.

```
Freq.   1  3  1  5  3  4  3  3  8  5  5  2  4  3  0  0
8                               +
7                               +
6                               +
5                +              +  +  +
4                +     +        +  +  +     +
3          +     +  +  +  +  +  +  +  +     +  +
2          +     +  +  +  +  +  +  +  +  +  +  +
1       +  +  +  +  +  +  +  +  +  +  +  +  +  +
--//----------------------------------------------------
        5  6  7  8  9  10 11 12 13 14 15 16 17 18 19 20
                         Test Scores

    Mean = 12.16   Variance = 12.42   St. Dev. = 3.52
```

Figure 3. Frequency distribution of Photophosphorylation test scores for written version group. + = 1 score, N = 50

The results of the ANOVA test are presented in Table I. The null hypotheses of no effect of media on achievement scores, no effect of task completion order on achievement scores, and no interaction effect of media and order on achievement scores, were all rejected at alpha = 0.05. The Factor A (media) hypothesis was also rejected at alpha = 0.01. As a result of rejecting these hypotheses, Duncan's New Multiple Range Test was employed to detect which group means differed; Table II presents these results. Significant differences were found to lie between both levels (WM and WL) of the W group and between the entire W group and the entire CAI group at the 0.05 level as indicated in Table II. At the 0.01 level only the WL group stood out as significantly different from the other three groups. After examining these general trends in the data, they were scrutinized more closely by means of item analyses.

The pertinent item analyses data for the class as a whole are presented in Table III. The KR (Kuder Richardson)-20 value at the top of the table is a measure of test reliability estimated on the basis of the consistency of student performance from item to item within the test (Ahmann and Glock, 1981). This value can theoretically range from -1 to 1, with these limits being perfect internal consistency, i.e. students consistently got all questions wrong or consistently got all questions right. The Photophosphorylation test had a KR-20 value of

```
Freq. 1   3   1   6   3   7   4   9   15  9   11  10  8   8   4   1
15                                    +
14                                    +
13                                    +
12                                    +
11                                    +       +
10                                    +       +   +
 9                                +   +   +   +   +
 8                                +   +   +   +   +   +   +
 7                        +       +   +   +   +   +   +   +
 6                +       +       +   +   +   +   +   +   +
 5                +       +       +   +   +   +   +   +   +
 4                +       +   +   +   +   +   +   +   +   +   +
 3        +       +   +   +   +   +   +   +   +   +   +   +   +
 2        +       +   +   +   +   +   +   +   +   +   +   +   +
 1    +   +   +   +   +   +   +   +   +   +   +   +   +   +   +   +
  --//-------------------------------------------------------------
      5   6   7   8   9   10  11  12  13  14  15  16  17  18  19  20
                              Test Score

      Mean = 13.48    Variance = 11.76    St. Dev. = 3.43
```

Figure 1. Frequency distribution of Photophosphorylation test scores for entire class. + = 1 score, N = 100.

Table II. Duncan's New Multiple Range Test for mean Photophosphorylation scores of the four treatment groups. CL = Computer/Lab 1st, CM = Computer/Module 1st, WM = Written/Module 1st, WL = Written/Lab 1st

Group		CL (14.80)	CM (14.80)	WM (13.60)	WL (10.72)	Crit. (.01)	Vals (.05)
CL	(14.80)	0	0	1.20*	4.08**		
CM	(14.80)	0	0	1.20*	4.08**	2.80	1.21
WM	(13.60)	0	0	0	2.88**	2.61	0.97
WL	(10.72)	0	0	0	0	2.29	0.58

14.80 14.80 13.60 10.72

* significant at alpha = 0.05
** significant at alpha = 0.01

0.666. Item difficulty indices indicate the proportion of students correctly answering each item out of 102 examinees. (Note: Item 20 was computed on the basis of 99 individuals. The computer assumed that the 3 people who did not answer the question did not have time to finish the test; the missing responses were not treated as incorrect answers by the computer for item analysis purposes. Responses missing from items 13 and 14 were treated as incorrect answers when computing item analysis data.) A large or small item difficulty indicates that the item was too hard or too easy respectively. Items with difficulty indices between 0.40 and 0.70 are considered at a "good" difficulty level for a norm-referenced achievement test (Ahmann and Glock, 1981). Items which fall in this range are indicated in Table III. Ahmann and Glock (1981) recommend that these values be considered rough approximations because we do not know whether the number of people who knew the answers was the same as the number of people who got them correct.

Item biserial correlation values provide an index of discrimination, or a measure of the degree to which students with higher test scores answer an item correctly and students with lower test scores answer an item incorrectly (Kehlberg and Flatham, 1969). Indices of discrimination are often determined by an internal consistancy method. That is, the scores from the test itself are used as internal criterion and divided into upper and lower groups (for example, the top and bottom 1/5). Maximum discriminating power of an item means everyone in the upper group answered the item correctly and everyone in the lower group answered it incorrectly (Ahmann and Glock, 1981). Thus, items with high biserial correlations are the best discriminators. The following criteria have been used in Table III: items with biserial correlations below 0.2 are considered poor discriminators, those between 0.2 and 0.299 are fair discriminators, and those above 0.3 are good discriminators (Ahmann and Glock, 1981). A negative value means the item is unsatisfactory at discriminating between students who know the material and those who do not; item 18 has both a negative reliability index and a negative biserial correlation. The item reliability indices are indicators of item effectiveness. This index takes into account biserial correlation and the proportions of students getting a question correct or incorrect.

Those items which have both a difficulty index between 0.4 - 0.7, and a biserial correlation above 0.3, have been tagged as good discriminators of moderate difficulty (Table III), i.e. good items relative to the others on the test. Ten of the 20 items on the test fit this category (Nos. 2, 6, 7, 10, 11, 14, 15, 16, 19, 20). Items 14 and 19 were included because they have high biserial correlations (0.504 and 0.688 respectively), with difficulties of 0.706 each. The worst item, in this respect, is number 18 with

Table III. Summary of item analyses performed on Photophosphorylation test scores for the whole class. N = no. students answering each item, DIF = item difficulty index, REL = item reliability index, BIS = item biserial correlation

KR-20 Reliability Coefficient = 0.666

Item #	N	DIF	REL	BIS
1	102	0.765	0.276	0.651+
2*	102	0.422<	0.265	0.537+
3	102	0.794	0.241	0.597+
4	102	0.843	0.256	0.704+
5	102	0.902	0.108	0.363+
6*	102	0.608<	0.256	0.525+
7*	102	0.637<	0.283	0.588+
8	102	0.784	0.265	0.645+
9	102	0.363	0.139	0.289
10*	102	0.657<	0.162	0.341+
11*	102	0.618<	0.354	0.729+
12	102	0.324	0.126	0.269
13	101	0.824	0.180	0.473+
14*	101	0.706	0.230	0.504+
15*	102	0.637<	0.268	0.558+
16*	102	0.686<	0.306	0.660+
17	102	0.765	0.260	0.613+
18	102	0.833	-0.013	-0.035
19*	102	0.706	0.314	0.688+
20*	99	0.598<	0.259	0.532+

* Good discrimination/difficulty level
< Item difficulty index between 0.4 - 0.7
+ Good discriminator (> 0.3)

DIF = 0.833, REL = -0.013 and BIS = -0.035.

In a manner similar to that discussed above, the data were separated into the CAI and W groups, and an item analysis was run on each of these. The item difficulty and item reliability indices are presented in Table IV. All difficulty indices were calculated on the basis of 51 individuals except item 20, for reasons explained earlier. The item reliability indices are presented to provide evidence that the items are still reliable when considered separately for each treatment group. Item difficulty indices in Table IV were used strictly for comparison purposes between the two groups. The test for the equality of two proportions was executed using the item difficulties of each group for each item. This test resulted in a z-score for each item; these were compared to the critical value of +/- 1.65 at the 0.05 level to conclude acceptance or rejection of the null hypothesis, DIF(CAI) <= DIF(W).

Six of 20 items (Nos. 3, 7, 11, 14, 19, 20) showed a significantly larger difficulty index for the CAI group than for the W group. Only item 18 showed a smaller difficulty index for the CAI group (0.824) than for the W group (0.843); however, a test against the null hypothesis, DIF(CAI) >= DIF(W), revealed that the values were not significantly different. Therefore the W group did not do significantly better than the CAI group on any of the items. Of the six items which showed a significant

Table IV. Summary of Item Difficulty, Reliability and Z-Score Data for the CAI and W groups taking the photophosphorylation test. N = no. students answering each item, DIF = item difficulty indices, REL = item reliability indices

	CAI			WRITTEN			
Item #	N	DIF	REL	N	DIF	REL	Z
1	51	0.765	0.326	51	0.765	0.280	0
2	51	0.490	0.151	51	0.353	0.339	-1.4
3	51	0.863	0.138	51	0.725	0.282	-1.72*
4	51	0.902	0.133	51	0.784	0.316	-1.64
5	51	0.941	0.090	51	0.863	0.090	-1.32
6	51	0.647	0.145	51	0.569	0.347	-0.81
7	51	0.725	0.150	51	0.549	0.347	-1.85*
8	51	0.843	0.293	51	0.725	0.229	-1.45
9	51	0.431	0.118	51	0.294	0.114	-1.44
10	51	0.686	0.226	51	0.627	0.110	-0.63
11	51	0.765	0.336	51	0.471	0.302	-3.06*
12	51	0.353	0.204	51	0.294	0.055	-0.64
13	50	0.863	0.138	51	0.784	0.197	-1.05
14	50	0.863	0.261	51	0.549	0.114	-3.48*
15	51	0.686	0.170	51	0.588	0.339	-1.03
16	51	0.745	0.290	51	0.627	0.312	-1.28
17	51	0.804	0.150	51	0.725	0.342	-0.94
18	51	0.824	0.051	51	0.843	-0.056	-0.26
19	51	0.784	0.205	51	0.627	0.369	-1.74*
20	50	0.800	0.287	49	0.429	0.124	-3.82*

* significant at the 0.05 level
critical z-score = +/- 1.65

difference, only item 3 was considered a poor discriminator (Table III). Therefore it was not considered a good item to yield information at the distracter level.

Items 7, 11, 14, 19 and 20 were further analyzed by looking at the percent distribution of people answering each distracter in both treatment groups. These data are presented in Tables V and VI. Shown for each group and each item are the number of people answering each item, the difficulty indices, and the proportion of students choosing each distracter. The latter can be considered the percentage distribution of student answers, if multiplied by 100. Also shown in these tables are the average total test scores of the people choosing each distracter. The mean scores are presented only for reference and not for comparative purposes. These means were transformed to standard z-scores having a normal distribution and a mean of zero, useful for relative comparisions between groups. The z-scores are useful for determining the distribution about the mean or the achievement level (based on Photophosphorylation test scores) of the students choosing each distracter. It must be kept in mind that the z-scores are useful for relative comparisons between groups, but not for absolute comparisons. The correct answers are indicated in the tables; for all items presented here, the correct answers were all chosen by the greatest proportion of students in each group.

An examination of the distracters of item 7 reveals that 27% of the W group tended to choose distracter B (Table V), compared to 12% choosing B in the CAI group. The z-scores of item 7 (Table V) indicate that the people choosing the correct answer in the W group generally scored higher on the test (z=0.46) relative to each other, than did the CAI group (z=0.02). Even though 14 people in the W group chose distracter B, the people who did, scored lower on the test (z=-0.75) relative to others in the W group, than did the 6 people choosing B in the CAI group (z=-0.54).

Table V reveals a similar pattern for item 11, with a higher percentage of people choosing the correct answer E in the CAI group (76%) than in the W group (47%). In the W group, 12 people (24%) also chose distracter C. No one in the CAI group chose distracter B, and the people who did choose B in the W group scored low on the test relative to others in the W group (z=-0.75). The z-scores for people in both groups choosing the correct answer were relatively close and above the mean.

A different pattern shows up in item 20 (Table V). One person in the CAI group and two in the W group did not answer the question. 39 of the students in the C group (78%) chose the correct answer, whereas the distribution for the W group was spread between distracters A, B and C (29%, 25% and 41% respectively). No one in the W group

Table V. Item statistics for items 7, 11, and 20, as calculated for both treatment groups. Shown are the proportion of students choosing each distracter (A - E) in each group, average test score means of the students who chose each distracter, N = no. students answering the item, DIF = item difficulty index, *correct answer

Item 7	N	DIF	A*	B	C	D	
COMP	51	0.725	0.73	0.12	0.04	0.12	Distrib.
			15.20	13.30	11.00	14.80	Mean scores
			0.02	-0.54	-1.35	0.02	Z-scores
WRIT	51	0.549	0.55	0.27	0.02	0.16	Dis.
			13.90	9.00	8.00	12.10	Means
			0.46	-0.75	-1.05	-0.17	Z

Item 11	N	DIF	A	B	C	D	E*	
COMP	51	0.765	0.06	0.00	0.10	0.08	0.76	Dis.
			13.30	0.00	12.60	10.00	15.60	Means
			-0.54	0.00	-0.54	-1.65	0.38	Z
WRIT	51	0.471	0.16	0.10	0.24	0.04	0.47	Dis.
			10.40	8.60	10.80	15.00	14.00	Means
			-0.54	-0.75	-0.35	0.75	0.46	Z

Item 20	N	DIF	A	B	C*	D	
COMP	50	0.800	0.04	0.14	0.78	0.02	Dis.
			10.50	12.40	15.50	12.00	Means
			-1.35	-1.01	0.38	-1.01	Z
WRIT	49	0.429	0.29	0.25	0.41	0.00	Dis.
			12.10	11.00	13.00	0.00	Means
			-0.17	-0.35	0.12	0.00	Z

chose distracter D. The z-scores of people choosing the correct answer was slightly above the mean (z=0.12). The z-score of the CAI group choosing the correct answer was relatively higher than the mean (z=0.38).

The data for item 14 are presented in Table VI. One person in the CAI group did not answer the question. 45 of 50 people in the CAI group chose the correct answer B, and no one chose either distracter C or D. No one in the W group chose distracter D either, and nearly as many people chose distracter A (41%) as chose the correct answer (55%) in this group. The z-score of students choosing the correct answer was 0.02 in the CAI group and 0.12 in the W group.

The choice distributions for item 19 (Table VI) show that the most people choosing an incorrect distracter in the W group chose distracter A (16%), whereas the same proportion of students in the CAI group chose distracter C. The remainder of the people not choosing the correct answer, was somewhat evenly distributed between distracters B and C in the W group. The z-score for the correct answer in the W group (0.46) is much higher than that for the CAI group (0.02).

In addition to statistical analyses, a few personal observations were made. The students were not asked to record how long it took them to complete the module; however, I found that it took most of them approximately 30

Table VI. Item statistics for items 14 and 19, as calculated for both treatment groups. Shown are the proportion of students choosing each distracter (A - D) in each group, average test score means of the students who chose each distracter, z-scores of each mean score, N = no. students answering each item, DIF = item difficulty index, *correct answer

Item 14	N	DIF	A	B*	C	D	
COMP	50	0.863	0.12	0.86	0.00	0.00	Distrib.
			11.70	15.30	0.00	0.00	Mean scores
			-1.01	0.02	0.00	0.00	Z
WRIT	51	0.549	0.41	0.55	0.04	0.00	Dis.
			11.20	12.70	14.50	0.00	Means
			-0.35	0.12	0.75	0.00	Z

Item 19	N	DIF	A	B	C	D*	
COMP	51	0.784	0.02	0.04	0.16	0.78	Dis.
			12.00	13.00	13.00	15.30	Means
			-1.01	-0.54	-0.54	0.02	Z
WRIT	51	0.627	0.16	0.10	0.12	0.63	Dis.
			11.00	7.20	9.30	13.80	Means
			-0.35	-1.35	-0.75	0.46	Z

minutes to run the computer program. Generally people reading the written version took less than 30 minutes. Noise in the lab did not seem to distract anyone working on the module or taking the quiz; it was kept relatively quiet. All of the labs seemed to react cooperatively to the evaluation except a handful of people in the Thursday evening and Friday afternoon labs who expressed the desire to leave the lab as soon as possible. No one seemed to have any problems with the programs and everything else ran smoothly. In the two labs that I taught, I received many positive comments about both forms of media to the effect that students felt they had learned photophosphorylation better than the first time they attempted to learn it. Overall, the general attitude toward the evaluation of the lecture instructor, graduate teaching assistants and students involved was positive during, and after the evaluation.

DISCUSSION

After analyzing the statistical and item analyses data, certain conclusions can be made regarding the question: "do differences in learning result from the use of CAI or written material?" This question is basically answered by the rejection of the ANOVA hypothesis, no effect of media on achievement scores, at the 0.01 level (Table I). Thus the computer group mean score of 14.8 was significantly greater than the 12.16 mean of the written group. This must be considered cautiously, as the KR-20 value for the test was 0.666, and 0.5 is considered low (Ahman and Glock, 1981). Despite the reliability of the test, however, some items showed a significant difference between groups. One would expect that if the test was modified and made more reliable, the differences between CAI and W group scores would be even more significant.

A look at the class statistics (Appendix H) reveals that this difference can not really be attributed to more biology/forestry majors (people who may have been previously exposed to photophosphorylation) in one group than the other. There are also no other imbalances between the two groups due to the random experimental design. A further investigation of why these differences exist must be made by analyzing the item analyses data.

Use of ANOVA also showed that there was a significant difference between the mean scores of the lab work first (12.76) and module first (14.2) groups (Table I). Again, I do not feel that this difference was caused by excessive imbalances of different individuals in the class. The factor which I would expect to cause this difference would be an excessive number of people from lab sections 3 and 5 in the lab-first group, but sections were basically evenly distributed. Since it was these sections in which I noticed anxiety about getting out of lab, I anticipated that these sections would rush through the evaluation. Perhaps this happened, but due to the experimental design it had little noticeable effect.

A further analysis of the ANOVA results revealed an interaction effect between the media and order of task completion. Duncan's New Multiple Range test pinpointed the interaction to the written group only (Table II). The mean scores of the CL and CM groups were equal at the 0.05 and 0.01 levels, with the WM and WL means not equal to each other or the CAI group at 0.05. At the 0.01 level, only the WL mean was significantly different from the mean. This implies that the order of task completion affected student achievement, if students learned using the written material. It appears as if task order specifically affects achievement if the written material is done after the lab work. This could be due to fatigue after doing the lab work, however the CL group would have also been affected in this manner. The CL mean score did not indicate this.

I believe the explanation lies in student motivation. According to Bernard (1965) motivation is provided by rewards, knowledge of progress and novelty. For one thing the program may have been considered more novel than the written version, even though the majority of students had used CAI throughout the previous month (Appendix I). I got this feeling from those people who had been assigned to read the written version, many of whom seemed openly disappointed (expressed with comments etc.) when they discovered they were assigned to read the written version. This, and the fact that I felt that students were starting to tire of CAI programs, worried me at the time. However, I did not observe that type of open disappointment in the computer group. Knowledge of progress was provided in both the computer and written versions by informing students of the correct answers to questions imbedded in the module. The big difference between the two was in terms of rewards, student responses could not be evaluated nor praised, etc. in the written version. These factors seemed to decrease motivation for the W group, thus affecting their learning and resultant achievement.

Even more specifically I feel that the students who read the written version after their lab work, became bored with the material more than the students who read it before the lab work. Also, by the time these students were ready to take the test they were probably anxious to leave, perhaps causing them to rush through the test questions. Even though these postulations may be based on subjective observation, I feel that motivation and boredom were factors in causing this difference between the WL group and the other three groups. The purpose of assigning lab-first and module-first groups was strictly for randomization, therefore, with this analysis aside I will focus on the differences between the computer and written version groups.

If differing group achievement can be attributable to certain features of either medium, this may be detected by analyzing group responses to individual items. It is the distracter/stem (question) quality which makes the ten questions marked in Table III, good discriminators. Basically the z-score means associated with the distracters of these items were all negative numbers, with a positive z-score being associated with the correct choice. Thus people who generally scored low on the test had a difficult time distinguishing the incorrect distracters from the correct answer. This means the distracters seemed plausible to students who did not possess the knowledge to answer the question. This is the sign of a multiple choice item which functions well with the test; it does a good job of distinguishing those who know the material from those who do not (Ahmann and Glock, 1981). Thus it is best to examine these items to determine where the group learning differences lie. The other items did not function as well on this test, therefore they may lead to false assumptions.

An attempt was made to determine why different numbers of people with differing test achievement levels chose certain distracters in items 7, 11, 20, 14 and 19. The choice distributions for item 7 (reproduced below) seemed to indicate that the students in the W group had a hard time determining whether 1 or 2 electrons were needed to form 1 NADPH, since most of them chose distracters A and B (Table V).

7. Which of the following is needed to form a molecule of NADPH from NADP+?

   >A. 2 electrons, 1 H+
   B. 1 electrons, 1 H+
   C. 1 electrons, 2 H+
   D. 2 electrons, 2 H+

(Note: distracters B and C used improper grammar, however this should have affected all groups equally, if at all; > indicates the correct answer.)

I believe that the simulated movement of electrons and H+ from water to NADP+, helped create an image in the minds of the CAI group individuals. The W group, however, had to rely totally on recall of verbal information, as nothing in the illustrations indicated the number of electrons needed to form NADPH. Duchastel (1978) reported that illustrations can teach by showing, and sometimes they can be more important in this respect than verbal descriptions. In addition, psychologists believe that learning with illustrations can facilitate later retrieval from memory (Paivio, 1975). I believe that the animated movement of electrons etc. on the monitor, and user control of each reaction, helped focus student attention on the critical points which were stressed in the text. This seemed to facilitate learning in the CAI group. The written version simply referred to the pathway illustration; lack of more involved pictorial information may have caused the W group to rely more on what they acquired from the text, to answer item 7. This is not to say that retention was improved in either group; investigation of this possibility is beyond the scope of this study.

It seems that mainly those people who scored high on the test in the W group, chose the correct answer to item 7. Whereas, in the CAI group, either students who answered correctly had scored near the mean, or they were widely distributed about the mean, resulting in a z-score of 0.02. According to Koran et al. (1980), low ability students benefit the most from cues which enable them to discriminate relevant from irrelevant information (such as the electron moving around the pathway). Thus low ability students may have learned the material by focusing on the cues, and the higher ability students learned it from the text (as in the W group), such that many students of all levels could answer item 7 correctly in the CAI group. If this is true, The combination of text with simulation could be a powerful tool in the classroom.

Item 11 (reproduced below) resulted in a large difference in difficulty indices between the CAI and W groups (76% and 47% respectively).

> 11. Which of the following is associated with the cyclic pathway of photophosphorylation?
>
> A. Q (plastoquinone)
> B. P680
> C. NADP+
> D. H+
> >E. ADP

The distribution of responses was more widely distributed among the incorrect distracters in the W group than in the CAI group (Table V). Thus it seems that many of the W group could not distinguish the correct answer, whereas the distracters must have seemed more obviously incorrect to most of the CAI group. The CAI group even totally eliminated distracter B as a possible choice. It appears that the major problem in the W group, was remembering whether ADP or NADP+ was the product of the cyclic pathway.

Again, I feel that this is related to the animation of the pathway, i.e. the computer version simulated an electron cycling around the cyclic pathway, thus producing ATP from ADP. Especially important here is the animated movement of ATP off of the video screen, thus simulating its use in the dark reactions. The pathway illustration in the written version merely showed a curved arrow with ADP producing ATP as a branch of the pathway. Those people in the W group who chose C (24%) seem to have been misled in their learning, perhaps by seeing NADP+ printed next to ferredoxin, appearing as if it were part of the cyclic pathway (page D4, Appendix D). Those W group students may have recalled the pictorial relationship instead of the text description. This seems odd, as it was stressed in the text, that NADP+ must be lacking in order for the cyclic pathway to function. Thus it seems as if some of the W group students did not pay attention to, or remember, what was in the text. Again, the students who seemed to have had this problem were those below the mean (z=-0.35).

Due to the CAI group z-score of 0.38 for the correct answer to item 11, I feel that this item relied on a different type of learning than did item 7. Since item 11 required broader knowledge (all components of the cyclic pathway) than item 7 (number of electrons and H+ ions needed to form NADPH), it seems that cues may not have played as big a role in item 11. Cues only aid in obtaining information directly from a cue, and do not produce general scanning behavior to pick up incidental information

(Kauchak et al.,1978). Therefore, I feel this resulted in fewer "low achievers" answering correctly in the CAI group, as had in item 7, thus the z-score was relatively higher (0.38 vs. 0.02) for the correct answer. Since no one specific cue could have provided a learner with all of the information necessary to answer this question correctly, some of the low ability learners were not as apt to learn or remember the pertinent information.

Item 20 (reproduced below) is the only one of the five items being discussed here, which was a higher level question. That is, it was not based on simple recall of knowledge, it also required some application of that knowledge. By recalling that the exciting of P680 by light causes water to split, and that NADP+ requires two hydrogens from water to form NADPH, one can apply this knowledge to answering the question.

20. How many times does a molecule of P680 (PS II) need to be activated by light to produce one molecule of NAPDH?

A. 0 (P680) is not involved in producing NADPH)
B. 1 time
>C. 2 times
D. 4 times

In addition to the fact that the proportion of students getting this item correct in the CAI group (78%) was almost twice that of the W group (41%), two people in the W group did not answer the question (Table V). This seems to imply that the W group, on the whole, found item 20 difficult. Another indicator of this fact is that the proportion of students choosing distracters A and B were nearly equal (29% and 25% respectively) and near that of the correct answer (41%) in the W group. The proportions in the CAI group were again distributed similarly to those in item 11.

The W group could only answer this item on the basis of verbal information, as the printed illustration in no way indicated how many times P680 is activated by light. The computer version, however, simulated light activating P680 twice, before one molecule of NADPH forms. Since the choice distributions seem to indicate that many of the W group students were answering the question based on intuition, instead of knowledge, perhaps they ruled out distracter D just because it seemed unlikely. Thus it appears that the W group either 1) did not learn the material necessary to answer this question, due to insufficient illustrations or 2) written material does a poor job of teaching concepts at a higher learning level. However, the latter is a broad conclusion to draw based on the results of one item, despite past findings that CAI can teach higher level concepts that books often can not (Bork, 1981).

Item 14 (reproduced below) also had a wide spread in difficulty indices (86% vs. 55%), and again the material was presented in different ways in each medium.

14. Based on the equation given in the module, how many electrons (total) can one molecule of water contribute to photophosphorylation?

    A. 1
    >B. 2
    C. 3
    D. 4

The computer program cued on water every time its two electrons had both been donated to P680, by reprinting the complete equation for the splitting of water, next to the water molecule. This animation and repetition seemed to aid learning in the CAI group. The W group, however, had to rely on learning it from the equation printed beneath the pathway illustration. Perhaps this difference caused the 21 W group students to choose distracter A. This item functioned as did item 7, in the respect that the CAI group z-score of those people correctly answering both items was 0.02. Since both questions relate to numbers of electrons, I again feel that the specific cue used in the computer program to illustrate this point may have aided learning in the "low achievers." Again, perhaps students in higher achievement levels acquired the information from the text. Thus a broad range of students (test score-wise) answered the question correctly.

Finally, an examination of item 19 (reproduced below) provides little conclusive evidence. The difficulty indices of the two groups did not vary much, but were significantly different (Table VI).

19. Which of the following correctly describes the sequence followed by electrons which leave P680 (PS II)?

    A. cytochromes, Q (plastoquinone), P700
    B. P700, Q, cytochromes
    C. cytochromes, P700, Q
    >D. Q, cytochromes, P700

The text of both media stress the order followed by electrons, in step-by-step descriptions. The only way for a student to put it together, is to watch the pathway simulation in the program or look at the pathway illustration in the written version. The only advantage had by the CAI group was that of seeing each step animated.

The z-scores for each distracter of item 19, in both groups, show a similar pattern to those in item 7. Especially in that z = 0.02 in the CAI group and 0.46 in the W group for the correct answer. Since this item was rather broad, as was item 11, I feel that cues may have been less significant here also, with animation and direction of movement being the keys.

The general conclusion to be drawn from the analysis of these items, is that the illustrations in each type of media formed the root of the learning differences between the groups. Paivio (1969) suggests that the effectiveness of pictures may be due to the possiblity that pictures are encoded in both verbal and non-verbal storage, with retrieval from both stores being possible. It is my feeling that the computer program offered illustrations far superior in usefulness (in terms of learning) and quality than the written version. For one thing, there was an illustration on nearly every page. The W group received few illustrations and were offered text discussions of things which were not illustrated. Researchers have proven that providing a learner with relevant pictures during a learning session facilitates science learning (Holliday, 1975; Rigney and Lutz, 1976). For another thing, the CAI pictures were sharp and appealing, with animation to create interest and focus attention on aspects discussed in the text. There were only four summary diagrams presented in the written version, placed at the beginning of each major section. Thus readers had to rely on their own motivation to flip the pages back and forth to reinforce what they had just read in the text. This is a common malady of textbooks, in that it is often too expensive to incorporate a profuse amount of quality illustrations throughout the text.

Questions incorporated into the modules may have also played a big role. Questions are supposed to keep the student thinking and provide regular reinforcement. However, the necessity of having to search out the answers may have stifled the usefulness of the questions, as W group students may have skipped looking at the answers, or even skipped the questions. With this in mind, it seems that module questions could have played a role in increasing the achievement of the CAI group. This may be a key to item 7, in which W group students had trouble determining if one or two electrons are used to form NADPH. A question in the module specifically asks where the second electron comes from. Perhaps many W group students did not attempt to answer this question. There were also questions dealing with P680's involvement in the cyclic pathway, and with the number of hydrogen ions needed to form NADPH. The point is that much pertinent information was given in each module as a result of students attempting to answer each question. However, such information was presented in the appendix of the written version. If it had been placed in the text it would have revealed the answers to the questions. If individuals in the W group never turned to the back page for the answers, they missed information needed to fulfill the learning objectives. Even though the CAI group could press return to pass the explanations which followed the questions, the material was easily accessed and required less effort to examine than did the written explanations. Also, students in the written group may have had the impression that information in the appendix was supplemental and not necessary for an understanding of the material.

Another difference between the CAI and written version questions dealt with their wording. Many of the questions in the computer version relied on action that had just occurred on the screen. The equivalent written version questions were worded such that the learner was told to assume that a particular action had just occurred. This could have curbed the learning effectiveness of the written version questions relative to the computer questions, for often students did not have as much to go on when answering them. Thus they may have had a hard time answering them correctly. Students in the written group may have become more discouraged with the questions than students in the computer group. This may have influenced the W group students to skip questions. This tends to be another problem commonly associated with textbooks; most books have to rely on student imagination to set the scene for questions. There is nothing wrong with this, but one can not be sure whether one is testing the student's understanding of the material or his/her imaginative ability. This is also a bias in the way the written version was developed; It was copied from the CAI program to make the two forms of media equivalent. The written version may have been a better teaching tool had it been developed independently of the CAI version.

Finally, the W group received relatively few cues throughout the module. They had to rely on their own interest to look at, nonetheless analyze, specific portions of the diagrams. In a study done by Kauchak et al. (1978), the use of cues in learning was tested on 4th - 6th graders. Three groups of students were all given a written description of a plant growth experiment and a graph of the results. Each group received either a specific cue, a general cue or no cue about the graph. Groups were then tested with questions related to the cue, questions incidental to the cue and general questions. The cued group did the best, but only on the cue-related questions. A similar study by Koran et al. (1980) dealt with high school students who were given cued and non-cued slides of monocots and dicots to study. The cued students achieved higher posttest scores than the non-cued. I feel that a similar thing happened in this study. Certain questions certainly dealt with information which was specifically cued in the computer module, and not cued in the written version. Thus a difference in learning was evidenced by significant differences in difficulty indices between the two groups, for those questions. I feel that the questions which did not yield significant differences in difficulty indices between the two groups were either poorly functioning questions and/or they did not require information which was accentuated by cues, animation or module questions, to be correctly answered.

A look at the item analyses for items 2, 6, 10, 15 and

16 (good discriminators but did not show a significant difference between groups) reveals limited differences in the proportion of students choosing each distracter, between groups. None of these questions address the same information; only questions 15 and 16 touch the same objective, but deal with different pathways. Of these, item 6 is the only one which may have been accentuated by animation in the CAI version. The information needed to answer the other items was not reinforced by cues etc. in the CAI version any more than it was in the written version. This seems to substantiate the idea that the items which were not significantly different between groups, did not rely on information which was highlighted by cues etc. in the CAI version.

SUMMARY and CONCLUSIONS

A CAI program presenting photophosphorylation at the level of general college biology was developed. From this, a printed version was made, almost verbatim. After using either the computer module or the written version in a laboratory environment, all students were tested using the same multiple choice objective test. The test results yielded certain conclusions about learning via CAI and text. On the whole it can be inferred that CAI induces better learning in students than written material, when teaching photophosphorylation, as measured by the test employed. This may also be true when teaching other biological pathways which lend themselves to animation. It was also concluded that, of all treatment groups, the students reading the written version after the lab work showed the poorest achievement. Thus, text which is modelled after CAI material and implemented directly after lab work, may reduce the ability of the material to induce learning.

Ten of the 20 questions were determined to be good discriminators, and 5 of these showed a significant difference in correct responses between the computer and written version groups. Ideally all questions on the test should have been good discriminators for the purposes of this evaluation. From analyzing these selected items at the distracter level, certain inferences about learning were made. It appears that illustrations can provide a learning advantage in use with certain topics; generally they prove to be most useful when presented with a verbal description. More specifically, animated pictures served to promote higher test achievement in this study. Those questions which relied on information which had to be obtained from illustrations, resulted in higher achievement in the CAI group than in the W group. The major difference between the illustrations in these two media was the animation of the computer version.

Cues in the illustrations also seem to play an important role. They were prevalent in the CAI program, and many of the questions which showed significant differences between groups dealt with topics which had been cued in the program but not in the written version. Also, those questions which seemed to rely on cues revealed a trend in z-scores for the correct answers. Based on student scores on this test, it seems that cues tend to aid learning in low achievers more than in high achievers.

Finally, the use of intermittant questions in the text of both modules seemed to be more useful in the CAI material than in the written version. Test questions which dealt with material that had been previously covered by questions in the module, resulted in a higher proportion of correct answers in the CAI group than in the W group. This suggests that perhaps questions are passed over in written material and important information is missed, whereas this is not easy to do with CAI material. Students reading the written material may suffer from decreased motivation to learn as a result of skipping questions; it has been proven that intermittant questions in the text can provide motivation.

It is important to note that the importance of cues, animation and effective questions can not be generalized to encompass all tutorial/simulation CAI programs. However, the learning differences between the CAI and written version groups in this specific study, as indicated by objective test scores, were mainly attributed to these factors. To test the application of the major inferences made here to other CAI and written material, further research is needed. The importance that simulation or animation plays in learning is of prime consideration. Both still and animated pathways could be presented to groups in the form of CAI. These situations could include or lack text descriptions and include or lack cues. It would also be interesting to test whether learning was affected by the lecture and reading assignment prior to the evaluation. It is important in such studies to use and revise the test to be used as the evaluation instrument, a number of times with the guidance of item analyses. This helps to insure a high test reliability and good discriminating questions which can be utilized to acquire reliable information.

Finally, continuing development and research need to go into other forms of media and instruction. Even though this study resulted in certain conclusions pertaining to the teaching functions of CAI and written material, it is important to note that the influences of lab work, lecture, previous readings, etc. can not be sorted out from what was learned from the module. Perhaps CAI functions best with text supplements prior to use. Just as other forms of media work best with certain types of information, perhaps CAI is useful only for teaching certain concepts. To continue effectively stimulating learning, all forms of media and teaching must be constantly improved, in order to meet new challenges and the needs of new students.

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Appendix A

Photophosphorylation Diskette

Attached to the following page is a 16 sector diskette created for use on an Apple II Plus Microcomputer. It contains all BASIC subprograms which constitute the educational program entitled Photophosphorylation.

A2

Appendix B

Photophosphorylation Subprogram Listings

The following BASIC program listings comprise the educational program entitled Photophosphorylation. The subprograms (page numbers in parentheses) in order are Photophos 1 (B2), Photophos 1.5 (B7), Photophos 2 (B13), Photophos 3 (B21), Photophos 4 (B27)and Photophos 5 (B33).

```
100  GOTO 200
110  POKE 103,1
120  CALL 1002
130  CALL 6144
140  PRINT  CHR$ (16): INPUT "PLEASE DON'T PRESS <RESET
> DURING THIS  PROGRAM! PRESS <RETURN
> TO RESTART THIS PART OF THE PROGRAM...";A$
200  REM  THIS PROGRAM WAS DEVELOPED BY THE SUMIT I COURSEWARE DEVELOPMENT
       PROJECT, DEPARTMENT OF BIOLOGICAL SCIENCES, MICHIGAN TECHNOLOGICAL U
     NIVERSITY, HOUGHTON, MI 49931
210  REM  THIS MATERIAL IS BASED UPON WORK SUPPORTED BY THE NATIONAL SCIEN
     CE FOUNDATION UNDER GRANT NUMBER SED-7919051
220  REM  ANY OPINIONS, FINDINGS, AND CONCLUSIONS OR RECOMMENDATIONS EXPRE
     SSED IN THIS PUBLICATION ARE THOSE OF THE AUTHORS AND DO NOT NECESSAR
     ILY REFLECT THE VIEWS OF THE NATIONAL SCIENCE FOUNDATION
230  REM   SUBPROGRAM (PHOTOPHOS 1) O           F PHOTOPHOSPHORYLATION
240  REM    BASED ON PUBLICATIONS BY STRYER (1981) AND LEHNINGER (1975)
250  REM   DESIGNED BY CATHERINE LEECE
260  REM  PROGRAMMED BY CATHERINE LEECE
270  REM  INTITIALIZE VARIABLES
280 V3$ =  CHR$ (16): PRINT V3$
290  PRINT  CHR$ (26); CHR$ (12)
300  REM  MAIN PROGRAM
310  VTAB 3: HTAB (14): PRINT "INTRODUCTION
"
320  VTAB 6: PRINT "   PHOTOSYNTHESIS IS THE CONVERSION OF  LIGHT ENERGY T
     O CHEMICAL ENERGY WITHIN APLANT. THE REACTIONS INVOLVED TAKE      PLA
     CE IN TWO STAGES.": GOSUB 1190
330  VTAB 1: HTAB (12): PRINT "LIGHT REACTIONS"
340  VTAB 4: PRINT "   BASICALLY, IN THE FIRST STAGE, LIGHT ENERGY IS USED
      TO CONVERT ADP
 TO ATP
 TO PROVIDE THE PLANT WITH USABLE ENERGY.   ALSO, NADP
+ IS CONVERTED TO NADPH

 TO    PROVIDE THE HYDROGEN AND ELECTRONS"
350  PRINT "NEEDED TO REDUCE CO
100 TO CARBOHYDRATES.  THESE REACTIONS REQUIRE LIGHT, THUS THEYARE CALLED
     THE LIGHT REACTIONS
 OF       PHOTOSYNTHESIS, OR PHOTOPHOSPHORYLATION
.": GOSUB 1190
360  VTAB 1: HTAB (12): PRINT "DARK REACTIONS"
370  VTAB 4: PRINT "   IN THE SECOND STAGE, THE ENERGY      PRODUCTS OF TH
     E LIGHT REACTIONS ARE     USED TO CONVERT CARBON DIOXIDE TO        CAR
     BOHYDRATES. PLANTS STORE ENERGY IN
380  PRINT "THE FORM OF CARBOHYDRATES. THE REACTIONSOF THE SECOND STAGE DO
      NOT REQUIRE       LIGHT, THUS THEY ARE CALLED THE DARK

390  PRINT "REACTIONS
 OF PHOTOSYNTHESIS; THEY       ACTUALLY TAKE PLACE UNDER LIGHT AND
 DARKCONDITIONS.": GOSUB 1190
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400  VTAB 4: INPUT "PRESS <RETURN
> TO SEE A SIMULATION OF   PHOTOSYNTHETIC PRODUCTS BEING FORMED    AND USE
     D";A$
410  GOTO 570
420  VTAB 1: HTAB (12): PRINT "KEEP IN MIND...": VTAB 4: HTAB (1): PRINT "
        EVEN THOUGH PRODUCTS APPEARED TO FORMONE AT A TIME IN THE SIMULATI
     ON YOU JUSTSAW, THESE AND OTHER REACTIONS OCCUR    SIMULTANEOUSLY IN
     THE PLANT CELL.
425  GOSUB 1190
430  VTAB 1: HTAB (14): PRINT "CHLOROPLASTS"
440  VTAB 4: PRINT "   PHOTOSYNTHESIS TAKES PLACE IN HIGHLY SPECIALIZED OR
     GANELLES, THE CHLOROPLASTSOR CHLOROPLASTIDS. CHLOROPLASTS ARE     FOU
     ND IN ALL HIGHER PLANTS, BRYOPHYTES"
450  PRINT "AND MOST ALGAE. CHLOROPLASTS EXIST IN   THE CYTOPLASM OF PHOTO
     SYNTHETIC CELLS,  SUCH AS LEAF CELLS. THE DARK AND LIGHT"
455  PRINT "
REACTIONS OCCUR IN ALL CHLOROPLASTS, BUTEACH OCCURS IN A DIFFERENT LOCATIO
     N     INSIDE THE ORGANELLE.": GOSUB 1190
460  VTAB 1: HTAB (13): PRINT "CHLOROPHYLL"
470  VTAB 4: PRINT "   THE PIGMENT CHLOROPHYLL IS FOUND IN  CHLOROPLASTS.
     IT EXISTS IN MANY FORMS   WHICH DIFFER IN THEIR STRUCTURE AND THE WAV
     ELENGTH OF LIGHT THEY ABSORB. THE    LEAVES OF MANY PLANTS ARE GREEN
     BECAUSE"
480  PRINT "THEY CONTAIN HIGH AMOUNTS OF CHLOROPHYLLRELATIVE TO OTHER PIGM
     ENTS. CHLOROPHYLL ABSORBS VIOLET, BLUE AND RED LIGHT AND  REFLECTS, O
     R TRANSMITS, GREEN LIGHT.": GOSUB 1190
490  VTAB 1: HTAB (12): PRINT "PIGMENT SYSTEMS"
500  VTAB 4: PRINT "   CHLOROPHYLL AND OTHER PIGMENTS       INVOLVED IN TH
     E LIGHT REACTIONS OF      PHOTOSYNTHESIS MAKE UP TWO PIGMENT SYS- TEM
     S. THESE SYSTEMS ARE CALLED PIGMENT  SYSTEM I AND PIGMENT SYSTEM II
. THEIR"
510  PRINT "FUNCTION IS TO ABSORB LIGHT THAT STRIKESTHE LEAF AND CONVERT T
     HE LIGHT TO       CHEMICAL ENERGY.": GOSUB 1190
520  VTAB 4: PRINT "   LET'S GO ON AND LOOK AT A SIMULATION OF THE PHOTOPH
     OSPHORYLATION PATHWAY IN  ACTION.": PRINT : PRINT "   DON'T EXPECT TO
      UNDERSTAND WHAT'S "
530  PRINT "HAPPENING ON THE SCREEN JUST YET. THIS  IS JUST TO GIVE YOU A
     FEELING FOR THE   PATHWAY AS A WHOLE. THEN WE WILL BREAK  IT DOWN INT
     O PARTS TO EXAMINE WHAT'S    HAPPENING AT THE MOLECULAR LEVEL."
540  PRINT : INPUT "WHEN YOU ARE READY TO GO ON...PRESS     <RETURN
>";A$
550  PRINT V3$: PRINT "PLEASE BE PATIENT WHILE THE PROGRAM IS  LOADING..."
     : PRINT  CHR$ (4);"RUN PHOTOPHOS 1.5": END
560  REM  PHOTOSYNTHESIS SUMMARY SIMULATION
570  PRINT V3$
580  VTAB 23: HTAB (6): PRINT "** PRESS <ESC
> KEY TO STOP **"
590  VTAB 20: PRINT  CHR$ (22)
600  HPLOT 39,30 TO 39,105 TO 99,105 TO 99,30 TO 39,30: HPLOT 179,30 TO 17
     9,105 TO 239,105 TO 239,30 TO 179,30
610  VTAB 8: HTAB (8): PRINT "LIGHT": HTAB (7): PRINT "REACTION": VTAB 8: HTAB
     (29): PRINT "DARK": HTAB (27): PRINT "REACTION"
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620  VTAB 1: HTAB (8): PRINT "LIGHT
": VTAB 16: HTAB (1): PRINT "H1000"
630  FOR U = 1 TO 20
640  GOSUB 1210: FOR S = 1 TO 2
650  HPLOT 66,8 TO 66,29 TO 70,24: HPLOT 62,24 TO 66,29
660  GOSUB 1210
670  VTAB 16: HTAB (1): PRINT "H1000"
680  VTAB 16: HTAB (5): SPEED= 150: PRINT "1JB0 21D0 + 2H+ + 1C00100"
690  GOSUB 1210
700  VTAB 16: HTAB (1): PRINT "H1000"
710  HCOLOR= 0: HPLOT 66,8 TO 66,29 TO 70,24: HPLOT 62,24 TO 66,29: HCOLOR=
     3
720  SPEED= 255: VTAB 15: HTAB (9): PRINT "1D0": HTAB (8): PRINT " ": GOSUB
     1240: VTAB 15: HTAB (9): PRINT " ": VTAB 13: HTAB (9): PRINT "1D0"
730  GOSUB 1230: VTAB 13: HTAB (9): PRINT " "
740  GOSUB 1210: VTAB 16: HTAB (9): PRINT " ": VTAB 15: HTAB (9): PRINT "
     1
D0": GOSUB 1240: VTAB 15: HTAB (9): PRINT " ": VTAB 13: HTAB (9): PRINT "
     1D0": GOSUB 1230: VTAB 13: HTAB (9): PRINT " "
750  IF  PEEK ( - 16384) = 155 THEN 1160
760  GOSUB 1210: VTAB 15: HTAB (13): PRINT "H+": HTAB (13): PRINT " ": GOSUB
     1240: VTAB 15: HTAB (13): PRINT "  ": VTAB 13: HTAB (13): PRINT "H+":
      GOSUB 1230: VTAB 13: HTAB (13): PRINT "  "
770  GOSUB 1210: VTAB 16: HTAB (14): PRINT "  ": VTAB 15: HTAB (13): PRINT
     "H+": GOSUB 1240: VTAB 15: HTAB (13): PRINT "  ": VTAB 13: HTAB (13):
      PRINT "H+": GOSUB 1230: VTAB 13: HTAB (13): PRINT "  "
780  GOSUB 1210: IF  PEEK ( - 16384) = 155 THEN 1160
790  NEXT S
800  VTAB 16: HTAB (5): PRINT "                        "
810  VTAB 6: HTAB (26): PRINT ">": HPLOT 100,43 TO 181,43
820  FOR Q = 1 TO 3
830  VTAB 5: HTAB (16): PRINT "P": GOSUB 1240: VTAB 5: HTAB (16): PRINT "
     TP
": GOSUB 1240: VTAB 5: HTAB (16): PRINT "ATP
": GOSUB 1240
840  FOR S = 16 TO 22: VTAB 5: HTAB (S): PRINT " ATP
": GOSUB 1240: NEXT : VTAB 5: HTAB (23): PRINT " AT
": GOSUB 1240: VTAB 5: HTAB (24): PRINT " A": GOSUB 1240: VTAB 5: HTAB (25
     ): PRINT " "
850  IF  PEEK ( - 16384) = 155 THEN 1160
860  NEXT Q: VTAB 11: HTAB (26): PRINT ">": HPLOT 100,83 TO 181,83
870  FOR T = 1 TO 2: VTAB 10: HTAB (16): PRINT "H": GOSUB 1240: VTAB 10: HTAB
     (16): PRINT "PH
": GOSUB 1240: VTAB 10: HTAB (16): PRINT "DPH
": GOSUB 1240: VTAB 10: HTAB (16): PRINT "ADPH
": GOSUB 1240: VTAB 10: HTAB (16): PRINT "NADPH

880  GOSUB 1240
890  FOR S = 16 TO 20: VTAB 10: HTAB (S): PRINT " NADPH
": GOSUB 1240: NEXT : VTAB 10: HTAB (21): PRINT " NADP
": GOSUB 1240: VTAB 10: HTAB (22): PRINT " NAD
": GOSUB 1240: VTAB 10: HTAB (23): PRINT " NA
"
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900  GOSUB 1240: VTAB 10: HTAB (24): PRINT " N
910  GOSUB 1240: VTAB 10: HTAB (25): PRINT " ": GOSUB 1240: IF  PEEK ( - 1
     6384) = 155 THEN 1160
920  NEXT T
930  HCOLOR= 0: HPLOT 100,43 TO 181,43: HTAB (26): VTAB 6: PRINT " ": HPLOT
     100,83 TO 181,83: HCOLOR= 3: HTAB (26): VTAB 11: PRINT " ": HPLOT 179
     ,30 TO 179,105
940  GOSUB 1210
950  HPLOT 242,0 TO 221,29: HPLOT 170,0 TO 192,29: FOR S = 1 TO 4: HTAB (2
     9): VTAB (S): PRINT "CO100": IF S = 1 THEN  GOSUB 1210: GOTO 970
960  GOSUB 1240
970  HTAB (29): VTAB (S): PRINT "     ": NEXT : HPLOT 179,30 TO 239,30
980  HCOLOR= 0: HPLOT 242,0 TO 221,29: HPLOT 170,0 TO 192,29: HCOLOR= 3
990  GOSUB 1210: VTAB 6: HTAB (15): PRINT "<": HPLOT 97,43 TO 178,43
1000  FOR Q = 1 TO 3: VTAB 5: HTAB (25): PRINT "A": GOSUB 1240: VTAB 5: HTAB
     (24): PRINT "AD": GOSUB 1240: VTAB 5: HTAB (23): PRINT "ADP
": GOSUB 1240
1010  FOR S = 22 TO 16 STEP  - 1: VTAB 5: HTAB (S): PRINT "ADP

 ": GOSUB 1240: NEXT : VTAB 5: HTAB (16): PRINT "DP
 ": GOSUB 1240: VTAB 5: HTAB (16): PRINT "P ": GOSUB 1240: VTAB 5: HTAB (1
     6): PRINT " "
1020  IF  PEEK ( - 16384) = 155 THEN 1160
1030  NEXT Q: GOSUB 1210
1040  HTAB (15): VTAB 11: PRINT "<": HPLOT 97,83 TO 178,83
1050  FOR Q = 1 TO 2
1060  VTAB 10: HTAB (25): PRINT "N
": GOSUB 1240: VTAB 10: HTAB (24): PRINT "NA
": GOSUB 1240: VTAB 10: HTAB (23): PRINT "NAD
": GOSUB 1240: VTAB 10: HTAB (22): PRINT "NADP
": GOSUB 1240: VTAB 10: HTAB (21): PRINT "NADP
+": GOSUB 1240
1070  FOR S = 20 TO 16 STEP  - 1: VTAB 10: HTAB (S): PRINT "NADP
+ ": GOSUB 1240: NEXT : VTAB 10: HTAB (16): PRINT "ADP
+ ": GOSUB 1240: VTAB 10: HTAB (16): PRINT "DP
+ ": GOSUB 1240: VTAB 10: HTAB (16): PRINT "P+ ": GOSUB 1240: VTAB 10: HTAB
     (16): PRINT "+ "
1080  GOSUB 1240: VTAB 10: HTAB (16): PRINT " "
1090  GOSUB 1240: IF  PEEK ( - 16384) = 155 THEN 1160
1100  NEXT Q
1110  HCOLOR= 0: HPLOT 97,43 TO 178,43: HPLOT 97,83 TO 178,83: HCOLOR= 3: VTAB
     6: HTAB (15): PRINT " ": VTAB 11: HTAB (15): PRINT " ": HPLOT 99,30 TO
     99,105
1120  HPLOT 208,106 TO 208,125 TO 212,120: HPLOT 208,125 TO 204,120: VTAB
     17: HTAB (27): PRINT "SUGAR OR": HTAB (28): PRINT "STARCH": GOSUB 120
     0: GOSUB 1200
1130  HCOLOR= 0: HPLOT 208,106 TO 208,125 TO 212,120: HPLOT 208,125 TO 204
     ,120: HCOLOR= 3: VTAB 17: HTAB (27): PRINT "        ": HTAB (28): PRINT
     "      ": GOSUB 1210
1140  IF  PEEK ( - 16384) = 155 THEN 1160
1150  NEXT U
1160  POKE  - 16368,0: VTAB 1: HTAB (8): PRINT "LIGHT
```

```
": GOSUB 1200: PRINT  CHR$ (25);V3$
1170  GOTO 420
1180  REM  PAUSE & PRESS RETURN SUBROUTINES
1190  VTAB 24: INPUT "PRESS <RETURN
> TO CONTINUE";A$: PRINT V3$: RETURN
1200  FOR PAUSE = 1 TO 1200: NEXT : RETURN
1210  FOR PA = 1 TO 600: NEXT : RETURN
1220  FOR PA = 1 TO 380: NEXT : RETURN
1230  FOR PA = 1 TO 500: NEXT : RETURN
1240  FOR PA = 1 TO 100: NEXT : RETURN
```

```
100  GOTO 200
110  POKE 103,1
120  CALL 1002
130  CALL 6144
140  PRINT  CHR$ (16): INPUT "PLEASE DON'T PRESS <RESET
> DURING THIS  PROGRAM! PRESS <RETURN
> TO RESTART THIS PART OF THE PROGRAM.";A$
200  REM  THIS PROGRAM WAS DEVELOPED BY THE SUMIT I COURSEWARE DEVELOPMENT
      PROJECT, DEPARTMENT OF BIOLOGICAL SCIENCES, MICHIGAN TECHNOLOGICAL U
     NIVERSITY, HOUGHTON, MI 49931
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     ILY REFLECT THE VIEWS OF THE NATIONAL SCIENCE FOUNDATION
230  REM   SUBPROGRAM (PHOTOPHOS 1.5) OF PHOTOPHOSPHORYLATION
240  REM    BASED ON PUBLICATIONS BY STRYER (1981) AND LEHNINGER (1975)
250  REM    DESIGNED BY CATHERINE LEECE
260  REM   PROGRAMMED BY CATHERINE LEECE
270  REM  INTITIALIZE VARIABLES
280 V3$ =  CHR$ (16): PRINT V3$:CUE = 0
290  PRINT  CHR$ (12)
300 F$ = "
1ABEIJ0"
310 B$ = "1 GHKL   M0"
320 E$ = "1AJEIB0"
400  REM   MAIN PROGRAM/NON-CYCLIC PATHWAY
410  PRINT  CHR$ (26); CHR$ (12): GOSUB 1290
420  VTAB 23: HTAB (6): PRINT "** PRESS <ESC
> KEY TO STOP **"
430  VTAB 14: HTAB (17): PRINT "LIGHT
"
440  VTAB 17: HTAB (7): PRINT "H1000"
450  FOR Q = 1 TO 40
460  GOSUB 1870: IF  PEEK ( - 16384) = 155 THEN 1220
470  VTAB 17: HTAB (31): PRINT ">": HPLOT 150,108 TO 212,131: GOSUB 1870
480  VTAB 17: HTAB (32): PRINT "P10230": GOSUB 1870: HCOLOR= 0: HPLOT 150,
     108 TO 212,131: VTAB 17: HTAB (31): PRINT " ": GOSUB 1880
490  IF Q = 1 THEN  HPLOT 227,67 TO 227,123
500  HCOLOR= 3: VTAB 9: HTAB (33): PRINT " ": GOSUB 1880
510  FOR S = 16 TO 9 STEP  - 1: HTAB (32): VTAB S + 1: PRINT "      ": VTAB
     S: HTAB (32): PRINT "P10230": GOSUB 1900: NEXT
520  IF  PEEK ( - 16384) = 155 THEN 1220
530  VTAB 9: HTAB (32): PRINT "      ": VTAB 8: HTAB (35): PRINT "P10230"
540  VTAB 7: HTAB (36): PRINT "1D0": GOSUB 1880: VTAB 7: HTAB (36): PRINT
     " ": VTAB 6: HTAB (35): PRINT "1D0": GOSUB 1880: VTAB 6: HTAB (35): PRINT
     " "
550  VTAB 6: HTAB (34): PRINT "1D0": GOSUB 1880: VTAB 6: HTAB (34): PRINT
     " ": VTAB 7: HTAB (33): PRINT "1D0": HTAB (35): PRINT "P10230+": GOSUB
     1880: VTAB 8: HTAB (33): PRINT "Q"
560  IF  PEEK ( - 16384) = 155 THEN 1220
570  VTAB 8: HTAB (35): PRINT "      ": FOR S = 9 TO 17: VTAB S: HTAB (32):
     PRINT "P10230+": GOSUB 1900: IF S < 17 THEN  VTAB S: HTAB (32): PRINT
    "      ": NEXT
580  IF CUE = 2 THEN 630
590  SPEED= 150: VTAB 17: HTAB (7): PRINT "H1000 1JB0 21D0 + 1C00100 + 2H+
    ": SPEED= 255
600  GOSUB 1870
610  GOSUB 1880: VTAB 17: HTAB (7): PRINT "H1000"
620  GOSUB 1870: GOSUB 1870
630  IF CUE = 2 THEN  VTAB 17: HTAB (15): PRINT " ":CUE = 0: GOTO 650
640  VTAB 17: HTAB (14): PRINT " "
650  VTAB 16: HTAB (15): PRINT "1D0": GOSUB 1880: IF  PEEK ( - 16384) = 15
    5 THEN 1220
660  GOSUB 1870: GOSUB 1870
670  FOR S = 15 TO 35: VTAB 16: HTAB (S): PRINT " ": VTAB 16: HTAB (S + 1)
    : PRINT "1D0": GOSUB 1900: NEXT
680  GOSUB 1880: VTAB 16: HTAB (36): PRINT " ": HTAB (36): PRINT " "
690  VTAB 7: HTAB (33): PRINT " ": GOSUB 1900
700 V = 7: FOR S = 32 TO 11 STEP  - 1: HTAB (S): VTAB V: PRINT "1D0": GOSUB
    1900: IF S <  > 11 THEN  HTAB (S): VTAB V: PRINT " "
710  IF  PEEK ( - 16384) = 155 THEN 1220
720  IF S < 31 THEN V = 8: IF S < 27 THEN V = 9: IF S < 22 THEN V = 10: IF
    S < 17 THEN V = 11: IF S < 13 THEN V = 12
730  NEXT
740  GOSUB 1880
750  VTAB 12: HTAB (11): PRINT " ": HTAB (10): PRINT " ": VTAB 8: HTAB (33
    ): PRINT "Q"
760  GOSUB 1870
770  VTAB 12: HTAB (28): PRINT "ADP
": GOSUB 1870: GOSUB 1870: VTAB 12: HTAB (22): PRINT "ATP
"; TAB( 28);"    "
780  GOSUB 1870: FOR S = 22 TO 37: VTAB 12: HTAB (S): PRINT " ATP
": GOSUB 1900: NEXT
790  VTAB 12: HTAB (38): PRINT " AT
": GOSUB 1900: VTAB 12: HTAB (39): PRINT " A
": GOSUB 1900: VTAB 12: HTAB (40): PRINT " ": GOSUB 1860
800  IF  PEEK ( - 16384) = 155 THEN 1220
810  VTAB 12: HTAB (40): PRINT "A": GOSUB 1900: VTAB 12: HTAB (39): PRINT
    "AD
": GOSUB 1900: VTAB 12: HTAB (38): PRINT "ADP
": GOSUB 1900
820  FOR S = 37 TO 28 STEP  - 1: VTAB 12: HTAB (S): PRINT "ADP
 ": GOSUB 1900: NEXT
830  HPLOT 108,106 TO 75,99
840  GOSUB 1870: VTAB 13: HTAB (6): PRINT "P1F330": GOSUB 1870: HCOLOR= 0:
     HPLOT 108,106 TO 75,99: GOSUB 1880
850  IF Q = 1 THEN  HPLOT 52,18 TO 52,95: VTAB 3: HTAB (8): PRINT " "
860  HCOLOR= 3: VTAB 13: HTAB (5): PRINT "P1F330 "
870  IF  PEEK ( - 16384) = 155 THEN 1220
880  HTAB (11): VTAB 12: PRINT " "
890  FOR S = 13 TO 3 STEP  - 1: HTAB (5): VTAB S + 1: PRINT "      ": VTAB S
    : HTAB (5): PRINT "P1F330": GOSUB 1900: NEXT
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900  VTAB 3: HTAB (3): PRINT "P1F330  ": GOSUB 1870
910  VTAB 2: HTAB (6): PRINT "1D0": GOSUB 1890: VTAB 2: HTAB (6): PRINT "
     ": VTAB 1: HTAB (7): PRINT "1D0": GOSUB 1890: VTAB 1: HTAB (7): PRINT
     " ": HTAB (8): VTAB 1: PRINT "1D0"
920  HTAB (8): PRINT "Z": VTAB 3: HTAB (3): PRINT "P1F330+"
930  GOSUB 1870: IF  PEEK ( - 16384) = 155 THEN 1220
940  VTAB 3: HTAB (3): PRINT "      ": VTAB 3: HTAB (4): PRINT "P1F330+"
950  FOR S = 3 TO 12: HTAB (4): VTAB S: PRINT "      ": HTAB (4): PRINT "P
     1F330+": GOSUB 1900: NEXT
960  VTAB 13: HTAB (4): PRINT "  P1F330+"
970  FOR S = 8 TO 12: VTAB 1: HTAB (S): PRINT " ": VTAB 1: HTAB (S + 1): PRINT
     "1D0": GOSUB 1900: NEXT
980  VTAB 1: HTAB (13): PRINT " ": VTAB 2: HTAB (8): PRINT "Z": VTAB 2: HTAB
     (14): PRINT "1D0": HTAB (14): PRINT "FERREDOXIN"
990  IF  PEEK ( - 16384) = 155 THEN 1220
1000  IF CUE = 3 THEN CUE = 0: GOTO 1560
1010  IF  INT (Q / 2) <  > Q / 2 THEN CUE = 2: VTAB 2: HTAB (14): PRINT "
     "; TAB( 16);"1D100": GOTO 1200
1020  VTAB 16: HTAB (26): PRINT "H+": HTAB (25): PRINT " ": VTAB 15: HTAB
     (26): PRINT "H+": HTAB (26): PRINT "  "
1030  FOR S = 26 TO 34: HTAB (S): VTAB 15: PRINT " H+": GOSUB 1900: NEXT
1040  FOR S = 15 TO 5 STEP  - 1: HTAB (35): VTAB S: PRINT "  ": HTAB (35):
      VTAB S - 1: PRINT "H+": GOSUB 1900: NEXT
1050  VTAB 17: HTAB (11): PRINT "                    "
1060  FOR S = 14 TO 21: VTAB 2: HTAB (S): PRINT "  1D D0": GOSUB 1900: NEXT

1070  IF  PEEK ( - 16384) = 155 THEN 1220
1080  VTAB 2: HTAB (23): PRINT " ": VTAB 5: HTAB (25): PRINT "1D0": GOSUB
     1900: VTAB 2: HTAB (25): PRINT " ": VTAB 5: HTAB (27): PRINT "1D0": GOSUB
     1900
1090  FOR S = 25 TO 29: VTAB 5: HTAB (S): PRINT "  1D D0": GOSUB 1890: NEXT

1100  VTAB 5: HTAB (33): PRINT " ": VTAB 1: HTAB (13): PRINT "           ":
      GOSUB 1880: VTAB 5: HTAB (31): PRINT "  1D0": VTAB 5: HTAB (33): PRINT
     " ": VTAB 3: HTAB (14): PRINT "FERREDOXIN"
1110  VTAB 4: HTAB (29): PRINT "NADP H
  ": GOSUB 1870: GOSUB 1870: VTAB 2: HTAB (29): PRINT "NADPH
": VTAB 4: HTAB (29): PRINT "      "
1120  IF  PEEK ( - 16384) = 155 THEN 1220
1130  GOSUB 1880: FOR S = 29 TO 35: VTAB 2: HTAB (S): PRINT " NADPH

": GOSUB 1900: NEXT
1140  VTAB 2: HTAB (36): PRINT " NADP
": GOSUB 1900: VTAB 2: HTAB (37): PRINT " NAD
": GOSUB 1900: VTAB 2: HTAB (38): PRINT " NA
": GOSUB 1900: VTAB 2: HTAB (39): PRINT " N": GOSUB 1900
1150  VTAB 2: HTAB (40): PRINT " ": GOSUB 1860
1160  IF (Q / 2) / 2 <  >  INT ((Q / 2) / 2) THEN CUE = 3: VTAB 3: HTAB (1
    3): PRINT " ": GOTO 1190
1170  VTAB 4: HTAB (40): PRINT "N": GOSUB 1900: VTAB 4: HTAB (39): PRINT "
    NP
": GOSUB 1900: VTAB 4: HTAB (38): PRINT "NAD
": GOSUB 1900: VTAB 4: HTAB (37): PRINT "NADP
": GOSUB 1900: VTAB 4: HTAB (36): PRINT "NADP
+": GOSUB 1900
1180  FOR S = 35 TO 29 STEP  - 1: VTAB 4: HTAB (S): PRINT "NADP+
 ": GOSUB 1900: NEXT
1190  IF  PEEK ( - 16384) = 155 THEN 1220
1200  NEXT Q
1210  REM  END SIMULATION / PRESENT MENU
1220  POKE  - 16368,0: VTAB 14: HTAB (17): PRINT "LIGHT
": GOSUB 1860
1230  VTAB 23: PRINT  CHR$ (5): VTAB 23: INPUT "PRESS <RETURN
> WHEN YOU HAVE FINISHED   LOOKING AT THE PATHWAY FOR NOW.";A$
1240  PRINT  CHR$ (25);V3$: PRINT "   NOW THAT YOU HAVE SEEN THE WHOLE
      PATHWAY, LET'S BREAK IT DOWN AND EXAMINETHE PARTS. WE WILL START BY
     LOOKING AT"
1250  PRINT "THE TWO PIGMENT SYSTEMS INVOLVED IN     PHOTOPHOSPHORYLATION,
      PIGMENTS SYSTEM I AND PIGMENT SYSTEM II
."
1255  PRINT : PRINT "YOU WILL GET A CHANCE TO REVIEW THIS    AGAIN AT THE
     END OF THE PROGRAM, AFTER  THE SUMMARY."
1260  PRINT : INPUT "PRESS <RETURN
> TO CONTINUE";A$
1270  PRINT V3$: PRINT "PLEASE BE PATIENT WHILE THE PROGRAM IS  LOADING...
     ": PRINT  CHR$ (4);"RUN PHOTOPHOS 2": END
1280  REM  DRAW PATHWAY SUBROUTINE
1290  PRINT  CHR$ (25);V3$: HCOLOR= 3: HTAB (1): VTAB 12: PRINT  CHR$ (23)
     ;"ENERGY
"; CHR$ (25)
1300  HTAB (1): VTAB 1: PRINT "HIGH": HTAB (8): PRINT "Z": HTAB (13): PRINT
     "2FERREDOXIN": HTAB (1): VTAB 17: PRINT "LOW"
1310  VTAB 3: HTAB (12): PRINT ">": HPLOT 162,20 TO 181,20
1320  HPLOT 57,11 TO 79,19
1330  VTAB 2: HTAB (27): PRINT F$
1340  VTAB 4: HTAB (29): PRINT "NADP
+"
1350  FOR S = 2 TO 15 STEP 3: HTAB (3): VTAB S: PRINT "-": NEXT
1360  HTAB (33): VTAB 8: PRINT "Q"
1370  VTAB 17: HTAB (32): PRINT "P10230"
1380  VTAB 13: HTAB (6): PRINT "P1F330+"
1390  VTAB 3: HTAB (8): PRINT "^"
1400  HPLOT 52,18 TO 52,92
1410  VTAB 9: HTAB (33): PRINT "^"
1420  HPLOT 227,67 TO 227,123
1430  VTAB 11: HTAB (19): PRINT "CYT"
1440  VTAB 13: HTAB (11): PRINT "<"
1450  VTAB 10: HTAB (24): PRINT B$
1460  HPLOT 221,62 TO 147,80: HPLOT 123,86 TO 72,100
1470  VTAB 9: HTAB (11): PRINT "CYT"
1480  VTAB 12: HTAB (28): PRINT "ADP
"
1490  VTAB 5: HTAB (14): PRINT E$
1500  VTAB 5: HTAB (16): PRINT "ADP
"
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1510  VTAB 12: HTAB (9): PRINT "1L0"
1520  HPLOT 102,25 TO 79,63: HPLOT 73,73 TO 63,87
1530  HPLOT 0,170 TO 279,170
1540  VTAB 19: PRINT  CHR$ (22): RETURN
1550  REM  CYCLIC PATHWAY
1560  FOR R = 1 TO 2: VTAB 2: HTAB (14): PRINT " ":H = 14
1570  IF  PEEK ( - 16384) = 155 THEN 1220
1580  FOR S = 4 TO 11: VTAB S: HTAB (H): PRINT "1D0": GOSUB 1900: VTAB S: HTAB
     (H): PRINT " "
1590  IF S < 7 THEN H = H - 1: GOTO 1610
1600  IF S > 7 AND S < 10 THEN H = H - 1: GOTO 1610
1610  NEXT
1620  VTAB 12: HTAB (10): PRINT "1D0": GOSUB 1880: VTAB 12: HTAB (10): PRINT
     " ": HTAB (10): PRINT " "
1630  VTAB 3: HTAB (14): PRINT "FERREDOXIN": VTAB 5: HTAB (16): PRINT "ADP

": GOSUB 1870: GOSUB 1870: VTAB 7: HTAB (16): PRINT "ATP
": VTAB 5: HTAB (16): PRINT "    "
1640  GOSUB 1870: FOR S = 16 TO 37: VTAB 7: HTAB (S): PRINT " ATP
": GOSUB 1900: NEXT
1650  IF  PEEK ( - 16384) = 155 THEN 1220
1660  VTAB 7: HTAB (38): PRINT " AT
": GOSUB 1900: VTAB 7: HTAB (39): PRINT " A": GOSUB 1900: VTAB 7: HTAB (40
     ): PRINT " ": GOSUB 1860
1670  VTAB 5: HTAB (40): PRINT "A": GOSUB 1900: VTAB 5: HTAB (39): PRINT "
     AD
": GOSUB 1900: VTAB 5: HTAB (38): PRINT "ADP
": GOSUB 1900
1680  FOR S = 37 TO 16 STEP  - 1: VTAB 5: HTAB (S): PRINT "ADP
 ": GOSUB 1900: NEXT
1690  IF  PEEK ( - 16384) = 155 THEN 1220
1700  HPLOT 108,106 TO 75,99: GOSUB 1870: VTAB 13: HTAB (6): PRINT "P1F33
     0": GOSUB 1870: HCOLOR= 0: HPLOT 108,106 TO 75,99: GOSUB 1880
1710  HCOLOR= 3: VTAB 13: HTAB (5): PRINT "P1F330 "
1720  HTAB (11): VTAB 12: PRINT " "
1730  FOR S = 13 TO 3 STEP  - 1: HTAB (5): VTAB S + 1: PRINT "      ": VTAB
     S: HTAB (5): PRINT "P1F330": GOSUB 1900: NEXT
1740  VTAB 3: HTAB (3): PRINT "P1F330  ": GOSUB 1870
1750  VTAB 2: HTAB (6): PRINT "1D0": GOSUB 1890: VTAB 2: HTAB (6): PRINT "
      ": VTAB 1: HTAB (7): PRINT "1D0": GOSUB 1890: VTAB 1: HTAB (7): PRINT
     " ": HTAB (8): VTAB 1: PRINT "1D0"
1760  GOSUB 1870: IF  PEEK ( - 16384) = 155 THEN 1220
1770  VTAB 3: HTAB (3): PRINT "       ": VTAB 3: HTAB (4): PRINT "P1F330+"
1780  FOR S = 3 TO 12: HTAB (4): VTAB S: PRINT "       ": HTAB (4): PRINT "
     P1F330+": GOSUB 1900: NEXT
1790  VTAB 13: HTAB (4): PRINT "  P1F330+"
1800  FOR S = 8 TO 12: VTAB 1: HTAB (S): PRINT " ": VTAB 1: HTAB (S + 1): PRINT
     "1D0": GOSUB 1900: NEXT
1810  VTAB 1: HTAB (13): PRINT " ": VTAB 2: HTAB (8): PRINT "Z": VTAB 2: HTAB
     (14): PRINT "1D0": HTAB (14): PRINT "FERREDOXIN"
1820  GOSUB 1870
1830  NEXT : VTAB 3: HTAB (13): PRINT "2"
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1840  VTAB 2: HTAB (14): PRINT " "; TAB( 16): PRINT "1D0": GOTO 1170
1850  REM   PAUSE SUBROUTINES
1860  FOR PAUSE = 1 TO 1200: NEXT : RETURN
1870  FOR PA = 1 TO 200: NEXT : RETURN
1880  FOR PA = 1 TO 150: NEXT : RETURN
1890  FOR PA = 1 TO 80: NEXT : RETURN
1900  FOR PA = 1 TO 55: NEXT : RETURN
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100  GOTO 200
110  POKE 103,1
120  CALL 1002
130  CALL 6144
140  PRINT  CHR$ (16): INPUT "PLEASE DON'T PRESS <RESET
> DURING THIS  PROGRAM! PRESS <RETURN
> TO RESTART THIS PART OF THE PROGRAM.";A$
200  REM  THIS PROGRAM WAS DEVELOPED BY THE SUMIT I COURSEWARE DEVELOPMENT
      PROJECT, DEPARTMENT OF BIOLOGICAL SCIENCES, MICHIGAN TECHNOLOGICAL U
     NIVERSITY, HOUGHTON, MI 49931
210  REM  THIS MATERIAL IS BASED UPON WORK SUPPORTED BY THE NATIONAL SCIEN
     CE FOUNDATION UNDER GRANT NUMBER SED-7919051
220  REM  ANY OPINIONS, FINDINGS, AND CONCLUSIONS OR RECOMMENDATIONS EXPRE
     SSED IN THIS PUBLICATION ARE THOSE OF THE AUTHORS AND DO NOT NECESSAR
     ILY REFLECT THE VIEWS OF THE NATIONAL SCIENCE FOUNDATION
230  REM   SUBPROGRAM (PHOTOPHOS 2) OF PHOTOPHOSPHORYLATION
240  REM    BASED ON PUBLICATIONS BY STRYER (1981) AND LEHNINGER (1975)
250  REM    DESIGNED BY CATHERINE LEECE
260  REM   PROGRAMMED BY CATHERINE LEECE
270  REM  INTITIALIZE VARIABLES
280 V3$ =  CHR$ (16): PRINT V3$
290  PRINT  CHR$ (12)
300 F$ = "
1ABEIJ0"
310 B$ = "1 GHKL   M0"
320 E$ = "1AJEIB0"
400  REM  MAIN PROGRAM
410  PRINT  CHR$ (26); CHR$ (12): GOSUB 1750
420  PRINT "THIS DIAGRAM REPRESENTS PART OF THE     PHOTOPHOSPHORYLATION P
     ATHWAY. THE       COMPONENTS OF THIS PATHWAY WERE DETER-  MINED THROU
     GH EXPERIMENTATION WITH      CHLOROPLASTS.": GOSUB 1970
430  PRINT "THE REACTIVE CHLOROPHYLL MOLECULE IN    PIGMENT SYSTEM I (PS I

) IS CALLED P1F33:"
440  VTAB 14: HTAB (8): PRINT "^": HTAB (7): PRINT "PS I
": GOSUB 1970
450  VTAB 14: HTAB (8): PRINT " ": HTAB (7): PRINT "    ": VTAB 19: PRINT
     "THE REACTIVE CHLOROPHYLL MOLECULE IN    PIGMENT SYSTEM II (PS II
) IS CALLED     PF10230."
460  VTAB 17: HTAB (24): PRINT "PS II >

": GOSUB 1970
470  VTAB 17: HTAB (24): PRINT "      "
480  VTAB 19: PRINT "WHEN THE APPROPRIATE COLOR OF LIGHT     STRIKES PS I
 OR PS II
, AN ELECTRON IN   THE REACTIVE MOLECULE (P1F330 OR P10230) IS RAISED TO A
     N EXCITED STATE.": GOSUB 1970
490  PRINT "THIS MEANS THAT THE REACTIVE MOLECULE ISRAISED ABOVE ITS GROUN
     D STATE TO A      HIGHER ENERGY LEVEL. THIS ACTIVATES THE ELECTRON SO
      IT MAY BE PASSED TO AN      ACCEPTOR MOLECULE.": GOSUB 1970
500  PRINT "AS WE LOOK AT EACH ELECTRON ACCEPTOR,  KEEP IN MIND THAT A MO
     LECULE WILL NOT   ACCEPT AN ELECTRON UNLESS IT IS ALREADY LACKING AN
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    ELECTRON.": GOSUB 1970
510  INPUT "TO SEE WHAT HAPPENS WHEN LIGHT STRIKES  PS II
, PRESS <RETURN
>.";A$
520  PRINT V3$: VTAB 14: HTAB (17): PRINT "
LIGHT
": GOSUB 1980
530  VTAB 17: HTAB (31): PRINT ">": HPLOT 150,108 TO 212,131: GOSUB 1980
540  VTAB 17: HTAB (32): PRINT "P10230": GOSUB 1980: HCOLOR= 0: HPLOT 150,
     108 TO 212,131: VTAB 17: HTAB (31): PRINT " ": GOSUB 1980
550  HPLOT 227,67 TO 227,123: HCOLOR= 3: VTAB 9: HTAB (33): PRINT " ": GOSUB
     1980
560  FOR S = 16 TO 9 STEP  - 1: HTAB (32): VTAB S + 1: PRINT "      ": VTAB
     S: HTAB (32): PRINT "P10230": GOSUB 2010: NEXT
570  VTAB 9: HTAB (32): PRINT "      ": VTAB 8: HTAB (35): PRINT "P10230"
580  VTAB 7: HTAB (36): PRINT "1D0": GOSUB 1990: VTAB 7: HTAB (36): PRINT
     " ": VTAB 6: HTAB (35): PRINT "1D0": GOSUB 1990: VTAB 6: HTAB (35): PRINT
     " "
590  VTAB 6: HTAB (34): PRINT "1D0": GOSUB 1990: VTAB 6: HTAB (34): PRINT
     " ": VTAB 7: HTAB (33): PRINT "1D0": HTAB (35): PRINT "P10230+"
600  GOSUB 1990: VTAB 8: HTAB (33): PRINT "Q"
610  VTAB 19: PRINT "P10230 HAS DONATED THE ELECTRON AND WILL  NOW RETURN
     TO A LOWER ENERGY LEVEL. THE + SIGN INDICATES THAT THE MOLECULE IS
     MISSING AN ELECTRON, THUS IT IS          POSITIVELY CHARGED.": GOSUB 1
     970
620  VTAB 8: HTAB (35): PRINT "       ": FOR S = 9 TO 17: VTAB S: HTAB (32):
      PRINT "P10230+": GOSUB 2010: IF S < 17 THEN  VTAB S: HTAB (32): PRINT
     "       ": NEXT
630  VTAB 19: INPUT "P10230 NOW DRAWS AN ELECTRON AWAY FROM A  MOLECULE OF
      WATER. THIS CAUSES THE WATERMOLECULE TO SPLIT, THUS OXYGEN IS
     RELEASED FROM THE PLANT. TO SEE THE      ELECTRON TRANSFER PRESS <RETU
     RN
>.";A$
640  PRINT V3$: SPEED= 100: VTAB 17: HTAB (7): PRINT "H1000 1JB0 21D0 + 1C
     00100 + 2H+": SPEED= 255
650  GOSUB 1980
660  VTAB 17: HTAB (14): PRINT " ": VTAB 16: HTAB (15): PRINT "1D0"
670  GOSUB 1980
680  FOR S = 15 TO 35: FOR PA = 1 TO 100: NEXT : VTAB 16: HTAB (S): PRINT
     " ": VTAB 16: HTAB (S + 1): PRINT "1
D0": NEXT
690  GOSUB 1990: VTAB 16: HTAB (36): PRINT " ": HTAB (36): PRINT " "
700  VTAB 19: PRINT "P10230 ACCEPTED THE ELECTRON IT NEEDED,   THUS IT RET
     URNED TO ITS GROUND STATE. ITWILL REMAIN AT THIS ENERGY LEVEL UNTIL
     IT PICKS UP MORE LIGHT WAVES OF THE     APPROPRIATE WAVELENGTH.": GOSUB
     1970
710  PRINT "MEANWHILE, THE EXCITED ELECTRON IS      PASSED BY 'Q', A MOLEC
     ULE OF PLASTO-    QUINONE, TO A SERIES OF CYTOCHROMES AND OTHER ELECT
     RON CARRIERS WHICH ACT AS    ELECTRON ACCEPTORS AND DONORS.": GOSUB 1
     970
720  PRINT "AS THE ELECTRON IS PASSED IT LOSES SOME OF ITS ENERGY TO EACH
     ELECTRON CARRIER. THIS ENERGY DRIVES THE SPONTANEOUS      'DOWNWARD M
    OVEMENT' OF ELECTRONS.": GOSUB 1970
730  PRINT "EVEN THOUGH THE ELECTRON LOSES ENERGY ASIT PASSES THROUGH THE
     CYTOCHROME CHAIN, IT IS STILL AT A RAISED ENERGY LEVEL,   RELATIVE TO
      ITS INITIAL ENERGY LEVEL,   WHEN IT IS FINALLY ACCEPTED BY P1F330.":
      GOSUB 1970
740  PRINT "DURING THE ELECTRON TRANSFER, SOME       ENERGY IS CAPTURED TO
     FORM A HIGH ENERGYMOLECULE.": PRINT : INPUT "PRESS <RETURN
> TO SEE THIS HAPPEN";A$
750  PRINT V3$: VTAB 7: HTAB (33): PRINT " ": HTAB (33): PRINT "Q": GOSUB
     2000
760 V = 7: FOR S = 32 TO 11 STEP  - 1: HTAB (S): VTAB V: PRINT "1D0": GOSUB
     2000: IF S <  > 11 THEN  HTAB (S): VTAB V: PRINT " "
770  IF S < 31 THEN V = 8: IF S < 27 THEN V = 9: IF S < 22 THEN V = 10: IF
     S < 17 THEN V = 11: IF S < 13 THEN V = 12
780  NEXT
790  GOSUB 1990
800  VTAB 12: HTAB (11): PRINT " ": HTAB (10): PRINT " "
810  GOSUB 1980
820  VTAB 12: HTAB (28): PRINT "ADP
": GOSUB 1980: VTAB 12: HTAB (22): PRINT "ATP
"; TAB( 28);"    "
830  GOSUB 1980: FOR S = 22 TO 37: VTAB 12: HTAB (S): PRINT " ATP
": GOSUB 2010: NEXT
840  VTAB 12: HTAB (38): PRINT " AT
": GOSUB 2010: VTAB 12: HTAB (39): PRINT " A": GOSUB 2010: VTAB 12: HTAB (
     40): PRINT " ": GOSUB 1980: GOSUB 1990
850  VTAB 12: HTAB (40): PRINT "A": GOSUB 2010: VTAB 12: HTAB (39): PRINT
     "AD
": GOSUB 2010: VTAB 12: HTAB (38): PRINT "ADP
": GOSUB 2010
860  FOR S = 37 TO 28 STEP  - 1: VTAB 12: HTAB (S): PRINT "ADP
 ": GOSUB 2010: NEXT
870  VTAB 9: HTAB (33): PRINT "^": HPLOT 227,67 TO 227,123
880  VTAB 19: PRINT "AS THE ELECTRON HAS PASSED ALONG THE    SERIES OF CYT
     OCHROMES, THE ENERGY NEEDEDTO JOIN ADP
 AND INORGANIC PHOSPHATE WAS TRAPPED. THUS A MOLECULE OF ATP
  WAS     FORMED.": GOSUB 1970
890  PRINT "WOULD YOU LIKE A DEFINITION OF ATP
": INPUT A$
900  IF  LEFT$ (A$,1) = "N" THEN  PRINT : PRINT "OKAY, WE WILL GO ON...": GOSUB
     1970: GOTO 940
910  IF  LEFT$ (A$,1) <  > "Y" THEN  PRINT : INPUT "PLEASE RE-ENTER YES OR
     NO...";A$: GOTO 900
920  PRINT V3$: PRINT "ATP
 FUNCTIONS AS THE MAJOR CARRIER OF   CHEMICAL ENERGY IN THE CELLS OF ALL
        LIVING ORGANISMS. AS IT TRANSFERS ENERGYTO OTHER MOLECULES IT LOSE
     S ITS TERMINALPHOSPHATE GROUP AND BECOMES ADP
.": GOSUB 1970
930  PRINT "ADP
 CAN ACCEPT CHEMICAL ENERGY BY       GAINING A PHOSPHATE GROUP, THUS IT
        BECOMES ATP
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. IN THE CASE OF PLANTS, ATP
 FORMS AT THE EXPENSE OF SOLAR ENERGY.": GOSUB 1970
940  PRINT "IT IS BECAUSE OF THIS LIGHT ACTIVATED   PHOSPHORYLATION OF ADP


 TO FORM ATP
, THATTHE LIGHT REACTIONS OF PHOTOSYNTHESIS   WERE NAMED 'PHOTO - PHOSPHOR
     YLATION.'": GOSUB 1970
950  PRINT "ATP
 AND ADP
 MOLECULES MOVED TO AND FROM THE PATHWAY TO REPRESENT THE USE OF ATP
 AND THE REPLENISHMENT OF ADP
 BY THE DARKREACTIONS OF PHOTOSYNTHESIS ELSEWHERE INTHE CHLOROPLAST.": GOSUB
     1970
960  VTAB 19: INPUT "NOW, WHAT WILL CAUSE P1F330 TO BE BOOSTED TO A HIGHER
      ENERGY LEVEL? ";A$
970  IF  LEFT$ (A$,2) = "LI" OR  LEFT$ (A$,3) = "PH" OR  LEFT$ (A$,3) = "S
     UN" THEN  PRINT : PRINT "YOU ARE CORRECT!": GOSUB 1970: GOTO 1010
975  IF  LEFT$ (A$,2) = "EN" THEN  PRINT : PRINT "YOU ARE CORRECT, IF YOU
     MEAN LIGHT      ENERGY.": GOSUB 1970: GOTO 1010
980  IF A$ = "" THEN  PRINT : INPUT "PLEASE TRY TO ANSWER THE QUESTION-";A
     $: GOTO 970
990  IF FLAG = 1 THEN  PRINT V3$: PRINT "YOU ARE INCORRECT AGAIN.": GOSUB
     1970: GOTO 1010
1000  PRINT V3$: INPUT "SORRY, YOU ARE INCORRECT. THINK ABOUT   WHAT HAPPE
     NED TO P10230 AND TRY TO ANSWER AGAIN-";A$:FLAG = 1: GOTO 970
1010  PRINT "THE COLOR OF LIGHT APPROPRIATE FOR PS I
 STRIKES A REACTIVE MOLECULE OF P1F330.    THUS AN ELECTRON IS EXCITED, CA
     USING    P1F330 TO BE RAISED TO A HIGHER ENERGY    LEVEL.": GOSUB 197
     0
1020  VTAB 19: PRINT "IF THE LIGHT SOURCE IS TURNED OFF, THE  ENTIRE PATHW
     AY 'SHUTS DOWN' AT THE      REACTIVE CHLOROPHYLL MOLECULES. THAT IS,N
     O ELECTRONS CAN BE PASSED FROM THESE   MOLECULES IN THE DARK.": GOSUB
     1970
1030  INPUT "WHAT MUST BE MISSING FROM A P1F330        MOLECULE, AT THE MO
     LECULAR LEVEL, BEFOREIT CAN ACCEPT AN ELECTRON FROM A CYTO-  CHROME M
     OLECULE? ";A$
1040  IF A$ = "" THEN  INPUT "PLEASE TRY TO ANSWER THE QUESTION-";A$: GOTO
     1040
1050  IF  LEFT$ (A$,4) = "AN E" OR  LEFT$ (A$,3) = "A E" OR  LEFT$ (A$,1) =
     "E" THEN  PRINT V3$: PRINT "'ELECTRON' IS CORRECT!": PRINT : GOTO 107
     0
1060  PRINT V3$: PRINT "SORRY, '";A$;"' IS INCORRECT.": PRINT : PRINT "REM
     EMBER, A MOLECULE CANNOT ACCEPT AN   ELECTRON UNLESS IT IS MISSING AN
           ELECTRON.": GOSUB 1970: GOTO 1080
1070  PRINT "YOU REMEMBERED THAT A MOLECULE CANNOT   ACCEPT AN ELECTRON UN
     LESS IT IS ALREADY MISSING AN ELECTRON.": GOSUB 1970
1080  INPUT "TO SEE WHAT HAPPENS WHEN LIGHT STRIKES  PS I
, PRESS <RETURN
>.";A$
1090  PRINT V3$: HPLOT 108,106 TO 75,99
1100  GOSUB 1980: VTAB 13: HTAB (6): PRINT "P1F330": GOSUB 1980: HCOLOR= 0
     : HPLOT 108,106 TO 75,99: GOSUB 1980
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1110  HPLOT 52,18 TO 52,95: VTAB 3: HTAB (8): PRINT " ": GOSUB 1980: HCOLOR=
     3
1120  HTAB (11): VTAB 12: PRINT " "
1130  FOR S = 13 TO 3 STEP  - 1: HTAB (6): VTAB S + 1: PRINT "      ": VTAB
     S: HTAB (6): PRINT "P1F330": GOSUB 2010: NEXT
1140  VTAB 3: HTAB (3): PRINT "P1F330   ": GOSUB 1980
1150  VTAB 2: HTAB (6): PRINT "1D0": GOSUB 1990: VTAB 2: HTAB (6): PRINT "
      ": VTAB 1: HTAB (7): PRINT "1D0": GOSUB 1990: VTAB 1: HTAB (7): PRINT
     " ": HTAB (8): VTAB 1: PRINT "1D0"
1160  HTAB (8): PRINT "Z": VTAB 3: HTAB (3): PRINT "P1F330+"
1170  GOSUB 1980: GOSUB 1990
1180  VTAB 3: HTAB (3): PRINT "   P1F330+": GOSUB 2010
1190  FOR S = 3 TO 12: HTAB (6): VTAB S: PRINT "       ": HTAB (6): PRINT "
     P1F330+": GOSUB 2010: NEXT
1200  VTAB 19: PRINT "P1F330 IS NOW AT A LOWER ENERGY LEVEL BUT WILL NOT R
     ETURN TO ITS GROUND STATE     UNTIL IT ACCEPTS ANOTHER ELECTRON.": GOSUB
     1970
1210  PRINT "THE MOLECULE 'Z' NOW PASSES THE ELECTRONDOWN AN ENERGY GRADIE
     NT TO FERREDOXIN,  AN IRON PROTEIN.": PRINT : INPUT "PRESS <RETURN
> TO SEE THE TRANSFER.";A$
1220  PRINT V3$
1230  FOR S = 8 TO 12: VTAB 1: HTAB (S): PRINT " ": VTAB 1: HTAB (S + 1): PRIN
     "1D:": GOSUB 2010: NEXT
1240  VTAB 1: HTAB (13): PRINT " ": VTAB 2: HTAB (8): PRINT "Z"; VTAB 2: HTAB
     (14): PRINT "1D0": HTAB (13): PRINT "FERREDOXIN"
1250  VTAB 3: HTAB (8): PRINT "^": HPLOT 52,18 TO 52,92
1260  VTAB 19: PRINT "IF THERE IS SUFFICIENT NADP
+ TO ACCEPT  ELECTRONS FROM FERREDOXIN, THEN         FERREDOXIN DONATES IT
     S ELECTRONS TO     NADP
+. FOR EVERY TWO ELECTRONS DONATED, ONE MOLECULE OF NADPH
 IS FORMED.": GOSUB 1970
1270  PRINT "WOULD YOU LIKE A DEFINITION OF NADP
": INPUT A$
1280  IF  LEFT$ (A$,1) = "N" THEN  PRINT : PRINT "OKAY, WE WILL CONTINUE D
     ISCUSSING THE   TWO ELECTRONS NEEDED TO FORM NADPH
.": GOSUB 1970: GOTO 1320
1290  IF  LEFT$ (A$,1) <  > "Y" THEN  PRINT : INPUT "PLEASE RE-ENTER YES O
     R NO...";A$: GOTO 1280
1300  PRINT V3$: PRINT "NAD
P IS AN ORGANIC MOLECULE THAT CARRIESELECTRONS FROM ELECTRON DONORS TO
        ELECTRON ACCEPTORS.": GOSUB 1970
1310  PRINT "IN THIS CASE, NADP
 ACCEPTS ELECTRONS    FROM FERREDOXIN AND CARRIES THEM TO THE PART OF THE
     CHLOROPLAST WHERE THE DARK  REACTIONS OCCUR.": GOSUB 1970
1315  PRINT "THE ELECTRONS ARE THEN DONATED TO AVAIL-ABLE ELECTRON ACCEPTO
     RS IN THE DARK     REACTIONS.": GOSUB 1970
1320  INPUT "FROM WHAT MOLECULE INVOLVED IN THIS     PATHWAY DO YOU THINK
     THE SECOND ELECTRONCOMES? ";A$
1330  IF A$ = "" THEN  PRINT : INPUT "PLEASE TRY TO ANSWER THE QUESTION-";
     A$: GOTO 1330
1340  IF  LEFT$ (A$,2) = "WA" OR  LEFT$ (A$,2) = "H2" OR  LEFT$ (A$,3) = "
     P68" THEN  PRINT : PRINT "'WATER' IS THE BEST ANSWER.": GOSUB 1970: GOTO
     1370
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1350  IF FLAG = 2 THEN  PRINT "YOU ARE INCORRECT AGAIN.": GOSUB 1970: GOTO
     1370
1360  PRINT V3$: PRINT "´";A$;"´ IS INCORRECT.": INPUT "THINK ABOUT WHERE
     THE FIRST ELECTRON    CAME FROM AND TRY TO ANSWER AGAIN-";A$:FLAG = 2
     : GOTO 1340
1370  PRINT V3$: PRINT "THE SECOND ELECTRON WILL COME FROM P10230,WHICH OR
     IGINALLY ACCEPTED IT FROM WATER.IT WILL FOLLOW THE SAME PATHWAY THAT
     THEFIRST ELECTRON DID BECAUSE A MOLECULE OFNADP
+ IS AVAILABLE TO ACCEPT IT.": GOSUB 1970
1380  PRINT "SINCE FERREDOXIN IS ONLY A ONE-ELECTRON CARRIER, TWO MOLECULE
     S OF IT ARE NEEDED,ONE FOR EACH ELECTRON. THESE ELECTRONS  THEN CONVE
     RGE TO FORM ONE MOLECULE OF   NADPH
 FROM NADP
+.": GOSUB 1970
1390  INPUT "A HYDROGEN ION IS ALSO NEEDED TO FORM   NADPH
 FROM NADP
+. OF THE MOLECULES WE   HAVE DISCUSSED SO FAR, WHICH DO YOU     THINK SUP
     PLIES THE HYDROGEN ION? ";A$
1400  IF A$ = "" THEN  PRINT : INPUT "PLEASE TRY TO ANSWER THE QUESTION-";
     A$: GOTO 1400
1410  IF  LEFT$ (A$,2) = "WA" OR  LEFT$ (A$,2) = "H2" THEN  PRINT "´WATER´
     IS THE CORRECT ANSWER AGAIN!": GOSUB 1970: GOTO 1430
1420  PRINT "´";A$;"´ IS INCORRECT.": GOSUB 1970
1430  PRINT "THERE MAY BE OTHER SOURCES OF HYDROGEN  IONS IN THE CHLOROPLA
     ST, BUT WATER      SPLITS AND DONATES THE HYDROGENS TO     NADP
+ WHEN LIGHT IS PRESENT.": GOSUB 1970
1440  VTAB 19: PRINT "LET´S ASSUME THAT THE SECOND ELECTRON   HAS ALREADY
     BEEN ACCEPTED BY A SECOND   MOLECULE OF FERREDOXIN.": PRINT : INPUT "
     TO ADD THE SECOND FERREDOXIN TO THE     PATHWAY, PRESS <RETURN
>";A$
1450  PRINT V3$: VTAB 1: HTAB (13): PRINT "FERREDOXIN 1D0": VTAB 20: INPUT
     "NOW, TO FORM NADPH
, PRESS <RETURN
>";A$
1460  PRINT V3$
1470  VTAB 16: HTAB (26): PRINT "H+": HTAB (25): PRINT " ": VTAB 15: HTAB
     (26): PRINT "H+": HTAB (26): PRINT "  "
1480  HCOLOR= 0: HPLOT 227,67 TO 227,123: HCOLOR= 3
1490  GOSUB 1980
1500  FOR S = 26 TO 34: HTAB (S): VTAB 15: PRINT " H+": GOSUB 2010: NEXT
1510  HPLOT 227,67 TO 227,123
1520  FOR S = 15 TO 5 STEP  - 1: HTAB (35): VTAB S: PRINT "  ": HTAB (35):
     VTAB S - 1: PRINT "H+": GOSUB 2010: NEXT
1530  FOR S = 14 TO 23: VTAB 2: HTAB (S): PRINT " 1D0": GOSUB 2000: NEXT
1540  VTAB 1: HTAB (24): PRINT " ": VTAB 4: HTAB (24): PRINT "1D0": GOSUB
     2000: VTAB 2: HTAB (24): PRINT " ": VTAB 5: HTAB (24): PRINT "1D0": GOSUB
     2000: VTAB 4: HTAB (24): PRINT " ": HTAB (26): PRINT "1D0": GOSUB 200
     0
1550  FOR S = 24 TO 29: VTAB 5: HTAB (S): PRINT "  1D D:": GOSUB 2000: NEXT

1560  VTAB 5: HTAB (33): PRINT " ": VTAB 1: HTAB (13): PRINT "          ":
     GOSUB 2000: VTAB 5: HTAB (31): PRINT "  1D0": VTAB 5: HTAB (33): PRINT
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    " ": VTAB 3: HTAB (13): PRINT "FERREDOXIN"
1570  VTAB 4: HTAB (29): PRINT "NADP H
  ": GOSUB 1980: VTAB 2: HTAB (29): PRINT "NADPH
": VTAB 4: HTAB (29): PRINT "      "
1580  GOSUB 1990: FOR S = 29 TO 35: VTAB 2: HTAB (S): PRINT " NADPH
": GOSUB 2010: NEXT
1590  VTAB 2: HTAB (36): PRINT " NADP
": GOSUB 2010: VTAB 2: HTAB (37): PRINT " NAD
": GOSUB 2010: VTAB 2: HTAB (38): PRINT " NA
": GOSUB 2010: VTAB 2: HTAB (39): PRINT " N": GOSUB 2010: VTAB 2: HTAB (40
     ): PRINT " ": GOSUB 1980: GOSUB 1990
1600  VTAB 4: HTAB (40): PRINT "N": GOSUB 2010: VTAB 4: HTAB (39): PRINT "
     NA": GOSUB 2010: VTAB 4: HTAB (38): PRINT "NAD
": GOSUB 2010: VTAB 4: HTAB (37): PRINT "NADP
": GOSUB 2010: VTAB 4: HTAB (36): PRINT "NADP
+": GOSUB 2010
1610  FOR S = 35 TO 29 STEP  - 1: VTAB 4: HTAB (S): PRINT "NADP
+ ": GOSUB 2010: NEXT
1620  VTAB 19: PRINT "THE MOVEMENT OF NADP
+ AND NADPH
        MOLECULES TO AND FROM THE PATHWAY REPRE-SENTED THE USE OF NADPH
 AND REPLENISH-  MENT OF NADP
+ BY THE DARK REACTIONS OF  PHOTOSYNTHESIS.": GOSUB 1970
1630  PRINT "WHEN TWO MOLECULES OF FERREDOXIN AGAIN  HAVE ONE ELECTRON EAC
     H TO DONATE, THEY  WILL PASS THEM TO NADP
+ IF IT IS AVAIL- ABLE.": GOSUB 1970
1640  PRINT "THE PATHWAY THAT WE JUST TRACED THROUGH,ENDING WITH THE FORMA
     TION OF NADPH
, IS  CALLED NON-CYCLIC
 PHOTOPHOSPHORYLATION. ": GOSUB 1970
1650  PRINT "IT IS CALLED 'NON-CYCLIC' BECAUSE       ELECTRONS ESSENTIALLY
      FLOW FROM WATER TONADP
+ WITHOUT CYCLING BACK TO P1F330.": GOSUB 1970
1660  PRINT  CHR$ (25);V3$
1670  PRINT "THAT'S IT FOR NON-CYCLIC PHOTOPHOS-     PHORYLATION. WOULD YO
     U LIKE TO": PRINT
1680  PRINT "    1) REVIEW THIS SECTION ON NON-CYCLIC       PHOTOPHOSPHORY
     LATION": PRINT : PRINT "    2) GO ON AND LEARN ABOUT CYCLIC
       PHOTOPHOSPHORYLATION.": PRINT : PRINT "OR  3) EXIT FROM THE PROGRAM
     .
1690  PRINT : INPUT "WHAT IS YOUR CHOICE (1, 2 OR 3)? ";A$: PRINT
1700  IF  VAL (A$) = 1 THEN 410: END
1710  IF  VAL (A$) = 2 THEN  PRINT "PLEASE BE PATIENT WHILE THE PROGRAM IS
       LOADING...": PRINT  CHR$ (4);"RUN PHOTOPHOS 3": END
1720  IF  VAL (A$) = 3 THEN  PRINT V3$: PRINT "I HOPE YOU BENEFITTED FROM
     THIS PROGRAM.": PRINT "THANK YOU.": END
1730  INPUT "THAT WAS NOT ONE OF THE CHOICES, PLEASE RE-ENTER-";A$: GOTO 1
     700: END
1740  REM  DRAW PATHWAY SUBROUTINE
1750  PRINT  CHR$ (25);V3$: HTAB (1): VTAB 12: PRINT  CHR$ (23);"ENERGY
"; CHR$ (25)
1760  HTAB (1): VTAB 1: PRINT "HIGH": HTAB (8): PRINT "Z": HTAB (13): PRINT
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     "FERREDOXIN": HTAB (1): VTAB 17: PRINT "LOW"
1770  VTAB 3: HTAB (12): PRINT ">": HPLOT 156,20 TO 181,20
1780  HPLOT 57,11 TO 79,19
1790  VTAB 2: HTAB (27): PRINT F$
1800  VTAB 4: HTAB (29): PRINT "NADP
+"
1810  FOR S = 2 TO 15 STEP 3: HTAB (3): VTAB S: PRINT "-": NEXT
1820  HTAB (33): VTAB 8: PRINT "Q"
1830  VTAB 17: HTAB (32): PRINT "P10230"
1840  VTAB 13: HTAB (6): PRINT "P1F330+"
1850  VTAB 3: HTAB (8): PRINT "^"
1860  HPLOT 52,18 TO 52,92
1870  VTAB 9: HTAB (33): PRINT "^"
1880  HPLOT 227,67 TO 227,123
1890  VTAB 11: HTAB (19): PRINT "CYT"
1900  VTAB 13: HTAB (11): PRINT "<"
1910  VTAB 10: HTAB (24): PRINT B$
1920  HPLOT 221,62 TO 147,80: HPLOT 123,86 TO 72,100
1930  VTAB 12: HTAB (28): PRINT "ADP
"
1940  HPLOT 0,140 TO 279,140
1950  VTAB 19: PRINT  CHR$ (22): RETURN
1960  REM  PAUSE & PRESS RETURN SUBROUTINES
1970  VTAB 24: INPUT "PRESS <RETURN
> TO CONTINUE";A$: PRINT V3$: RETURN
1980  FOR PAUSE = 1 TO 1200: NEXT : RETURN
1990  FOR PA = 1 TO 400: NEXT : RETURN
2000  FOR PA = 1 TO 180: NEXT : RETURN
2010  FOR PA = 1 TO 100: NEXT : RETURN
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100  GOTO 200
110  POKE 103,1
120  CALL 1002
130  CALL 6144
140  PRINT  CHR$ (16): INPUT "PLEASE DON'T PRESS <RESET
> DURING THIS  PROGRAM! PRESS <RETURN
> TO RESTART THIS PART OF THE PROGRAM.";A$
200  REM  THIS PROGRAM HAS DEVELOPED BY THE SUMIT I COURSEWARE DEVELOPMENT
       PROJECT, DEPARTMENT OF BIOLOGICAL SCIENCES, MICHIGAN TECHNOLOGICAL U
     NIVERSITY, HOUGHTON, MI 49931
210  REM  THIS MATERIAL IS BASED UPON WORK SUPPORTED BY THE NATIONAL SCIEN
     CE FOUNDATION UNDER GRANT NUMBER SED-7919051
220  REM  ANY OPINIONS, FINDINGS, AND CONCLUSIONS OR RECOMMENDATIONS EXPRE
     SSED IN THIS PUBLICATION ARE THOSE OF THE AUTHORS AND DO NOT NECESSAR
     ILY REFLECT THE VIEWS OF THE NATIONAL SCIENCE FOUNDATION
230  REM    SUBPROGRAM (PHOTOPHOS 3) OF PHOTOPHOSPHORYLATION
240  REM    BASED ON PUBLICATIONS BY STRYER (1981) AND LEHNINGER (1975)
250  REM    DESIGNED BY CATHERINE LEECE
260  REM   PROGRAMMED BY CATHERINE LEECE
270  REM  INTITIALIZE VARIABLES
280 V3$ =  CHR$ (16): PRINT V3$
290 SC(1) = 0:SC = 0: PRINT  CHR$ (12):CUE = 0
300 F$ = "
1ABEIJ0"
310 B$ = "1 GHKL   M0"
320 E$ = "1AJEIB0"
400  REM  MAIN PROGRAM
410  PRINT  CHR$ (26); CHR$ (12): GOSUB 2010
420  VTAB 18: PRINT "THIS PATHWAY REPRESENTS WHAT BIOLOGISTS BELIEVE TO BE
       CYCLIC
 PHOTOPHOS-          PHORYLATION. NOTICE THAT IT CONTAINS    PORTIONS OF TH
      E NON-CYCLIC PATHWAY.": GOSUB 2210
430  VTAB 18: PRINT "BIOLOGISTS BELIEVE THE PLANT UTILIZES   THIS PATHWAY
     WHEN NADP
+ IS NOT AVAILABLETO ACCEPT ELECTRONS FROM FERREDOXIN.": GOSUB 2210
440  PRINT "NADP
+ WILL BE REMOVED FROM THIS PICTURE BECAUSE WE WOULD LIKE TO SEE WHAT
       HAPPENS WHEN IT IS NOT AVAILABLE TO THE PHOTOPHOSPHORYLATION REACTI
     ONS.": INPUT "PRESS <RETURN
> TO DO SO.";A$
450  PRINT V3$: FOR S = 2 TO 4: VTAB S: HTAB (23): PRINT "           ": NEXT

460  VTAB 18: PRINT "LET'S ASSUME THAT AN ELECTRON HAS       ALREADY BEEN
     BOOSTED TO A HIGHER ENERGY LEVEL BY LIGHT, AND PASSED FROM WATER TOFE
     RREDOXIN VIA NON-CYCLIC PHOTOPHOS-    PHORYLATION."
470  VTAB 24: INPUT "TO SEE THE ELECTRON, PRESS <RETURN
>";A$: PRINT V3$
480  VTAB 2: HTAB (14): PRINT "1D:0": HTAB (13): PRINT "FFERREDOXIN"
490  VTAB 18: PRINT "THIS MEANS THAT FERREDOXIN NEEDS TO     DONATE THE EX
     CITED ELECTRON TO AN       ACCEPTOR SO IT CAN BECOME A STABLE      MO
     LECULE.": GOSUB 2210
500  VTAB 18: PRINT "SINCE NADP
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+ IS UNAVAILABLE, THE ELECTRONIS DONATED TO A CHAIN OF VARIOUS CYTO-  CHRO
     ME MOLECULES.": GOSUB 2210
510  VTAB 18: PRINT "AS IN THE NON-CYCLIC PATHWAY, THE       ELECTRON LOSE
     S SOME OF ITS ENERGY TO    EACH CYTOCHROME, AND SOME OF ITS ENERGY IS
      TRAPPED TO FORM A MOLECULE OF ATP
.": GOSUB 2210
520  VTAB 18: PRINT "BECAUSE P1F330 DONATED ITS ELECTRON TO    FERREDOXIN
     WHEN ACTIVATED BY LIGHT, IT  HAS A NEED FOR AN ELECTRON. THEREFORE
     IT ACCEPTS THE ONE PASSED 'DOWN' THROUGHTHE CYTOCHROME CHAIN.": GOSUB
     2210
530  VTAB 18: PRINT "UNLIKE THE FORMATION OF NADPH
, ONLY ONE
 MOLECULE OF FERREDOXIN IS NEEDED TO     DONATE AN ELECTRON THROUGH THE CY
     TO-    CHROME CHAIN BACK TO P1F330.
535  INPUT "TO SEE FERREDOXIN DONATE THE ELECTRON,  PRESS <RETURN
>...";A$
540  PRINT V3$
550  VTAB 2: HTAB (14): PRINT " ":H = 14
560  FOR S = 4 TO 11: VTAB S: HTAB (H): PRINT "1D0": GOSUB 2250: VTAB S: HTAB
     (H): PRINT " "
570  IF S < 7 THEN H = H - 1: GOTO 590
580  IF S > 7 AND S < 10 THEN H = H - 1: GOTO 590
590  NEXT
600  VTAB 12: HTAB (10): PRINT "1D:0": GOSUB 2230: VTAB 12: HTAB (10): PRINT
     " ": HTAB (10): PRINT " "
610  VTAB 3: HTAB (13): PRINT "FERREDOXIN": GOSUB 2230: VTAB 5: HTAB (16):
      PRINT "ADP
": GOSUB 2220: VTAB 7: HTAB (16): PRINT "ATP
": VTAB 5: HTAB (16): PRINT "   "
620  GOSUB 2230: FOR S = 16 TO 37: VTAB 7: HTAB (S): PRINT " ATP
": GOSUB 2260: NEXT
630  VTAB 7: HTAB (38): PRINT " AT
": GOSUB 2260: VTAB 7: HTAB (39): PRINT " A
": GOSUB 2260: VTAB 7: HTAB (40): PRINT " ": GOSUB 2220: GOSUB 2230
640  VTAB 5: HTAB (40): PRINT "A": GOSUB 2260: VTAB 5: HTAB (39): PRINT "
     AD
": GOSUB 2260: VTAB 5: HTAB (38): PRINT "ADP
": GOSUB 2260
650  FOR S = 37 TO 16 STEP  - 1: VTAB 5: HTAB (S): PRINT "ADP
 ": GOSUB 2260: NEXT
660  IF CUE <  > 0 THEN  RETURN
670  VTAB 18: PRINT "THE FORMATION OF ATP
 IN THE CYCLIC PATH-WAY KEEPS ATP
 SUPPLIED TO THE CELL IN   THE ABSENCE OF NON-CYCLIC PHOTOPHOS-    PHORYLA
     TION.": GOSUB 2210
680  PRINT "IF THERE IS A SURPLUS OF ATP

, IT CAN BE USED FOR OTHER SYNTHETIC PROCESSES, IN  ADDITION TO THE DARK R
     EACTIONS.": GOSUB 2210
690  INPUT "IS P1F330 NOW IN ITS GROUND STATE? ";A$
700  IF A$ = "" THEN  PRINT : INPUT "PLEASE TRY TO ANSWER THE QUESTION-";A
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     $: GOTO 700
710  IF  LEFT$ (A$,1) = "Y" THEN  PRINT : PRINT "YOU ARE CORRECT.": GOSUB
     2210: GOTO 730
720  PRINT "YOU ARE INCORRECT. THINK ABOUT WHAT     CAUSED P1F330 TO RETUR
     N TO ITS GROUND     STATE IN NON-CYCLIC PHOTOPHOS-          PHORYLATI
     ON.": GOSUB 2210
730  PRINT "SINCE P1F330 ACCEPTED THE ELECTRON THAT   PASSED THROUGH THE C
     YTOCHROME CHAIN, IT FULFILLED ITS NEED FOR AN ELECTRON. THUSIT RETURN
     ED TO ITS GROUND STATE ENERGY  LEVEL.": GOSUB 2210
740  INPUT "IS PS II
(P10230) INVOLVED IN CYCLIC      PHOTOPHOSPHORYLATION? ";A$
750  IF A$ = "" THEN  PRINT : INPUT "PLEASE TRY TO ANSWER THE QUESTION-";A
     $
760  IF  LEFT$ (A$,1) = "N" THEN  PRINT : PRINT "YOU ARE CORRECT.": GOSUB
     2210: GOTO 780
770  PRINT : PRINT "YOUR ANSWER IS INCORRECT.": GOSUB 2210
780  PRINT "THE ELECTRON WHICH FILLS THE 'ELECTRON  HOLE' IN P1F330 (PS I
) IS CONSTANTLY      RECYCLED, THUS THE REACTIVE MOLECULE IN PS II
(P10230) IS NOT NEEDED TO DONATE AN ELECTRON.": GOSUB 2210
790  PRINT "P10230 WILL STILL BE ACTIVATED WHEN LIGHT STRIKES PS II
, BUT IT WILL NOT BE ABLE  TO PASS ITS EXCITED ELECTRON VERY FAR   ALONG T
     HE NON-CYCLIC PATHWAY WHEN THE   PLANT IS UTILIZING THE CYCLIC PATHWA
     Y.": GOSUB 2210
800  INPUT "PRESS RETURN TO SIMULATE LIGHT STRIKING P1F330...";A$
810  PRINT V3$
820  VTAB 13: HTAB (19): PRINT "LIGHT
": GOSUB 2220
830  VTAB 13: HTAB (10): PRINT "<": HPLOT 125,99 TO 65,99: GOSUB 2220: VTAB
     13: HTAB (6): PRINT "P1F330": GOSUB 2220: HCOLOR= 0: HPLOT 125,99 TO
     65,99: VTAB 13: HTAB (10): PRINT " ": GOSUB 2220
840  HPLOT 52,18 TO 52,95: VTAB 3: HTAB (8): PRINT " ": GOSUB 2220: HCOLOR=
     3: VTAB 13: HTAB (5): PRINT "P1F330 "
850  FOR S = 13 TO 3 STEP  - 1: HTAB (5): VTAB S + 1: PRINT "      ": VTAB S
: HTAB (5): PRINT "P1F330": GOSUB 2260: NEXT
860  VTAB 3: HTAB (3): PRINT "P1F330  ": GOSUB 2220
870  VTAB 2: HTAB (6): PRINT "1D10": GOSUB 2230: VTAB 2: HTAB (6): PRINT "
      ": VTAB 1: HTAB (7): PRINT "1D0": GOSUB 2230: VTAB 1: HTAB (7): PRINT
     " ": HTAB (8): VTAB 1: PRINT "1D0"
880  HTAB (8): PRINT "Z": VTAB 3: HTAB (3): PRINT "P1F330+": GOSUB 2220
890  VTAB 3: HTAB (3): PRINT "      ": VTAB 3: HTAB (4): PRINT "P1F330+"
900  FOR S = 3 TO 12: HTAB (4): VTAB S: PRINT "       ": HTAB (4): PRINT "P
     1F330+": GOSUB 2260: NEXT
910  VTAB 13: HTAB (4): PRINT "  P1F330+"
920  FOR S = 8 TO 12: VTAB 1: HTAB (S): PRINT " ": VTAB 1: HTAB (S + 1): PRINT
     "1D0": GOSUB 2250: NEXT
930  VTAB 1: HTAB (13): PRINT " ": VTAB 2: HTAB (8): PRINT "Z": VTAB 2: HTAB
     (14): PRINT "1D0": HTAB (13): PRINT "FERREDOXIN"
940  VTAB 3: HTAB (8): PRINT "^": HPLOT 52,18 TO 52,95
950 CUE = 1: GOSUB 540
960  VTAB 18: PRINT "AS LONG AS 1) NADP
+ MOLECULES ARE       UNAVAILABLE AND 2) LIGHT OF THE APPRO-  PRIATE WAVEL
     ENGTH IS PRESENT, THE       EXCITED ELECTRON WILL CONTINUE TO CYCLE."
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    : GOSUB 2210
970  VTAB 19: PRINT "THIS ENDS THE EXPLANATION OF CYCLIC     PHOTOPHOSPHOR
    YLATION. NEXT YOU WILL BE  PRESENTED WITH 5 QUESTIONS. EACH QUES-  TI
    ON MAY DEAL WITH THE CYCLIC OR NON-   CYCLIC PATHWAYS, OR BOTH.": GOSUB
    2210
972  INPUT "HAVE YOU TAKEN THE UPCOMING QUIZ BEFORE (I.E. WILL THIS BE A R
    EVIEW FOR YOU)?   ";A$
973  PRINT V3$: IF  LEFT$ (A$,1) = "Y" THEN 1400
974  IF  LEFT$ (A$,1) <  > "N" THEN  PRINT : INPUT "PLEASE RE-ENTER-";A$: GOTO
    973
980  VTAB 19: INPUT "WHEN YOU ARE THROUGH EXAMINING THE      CYCLIC PATHWA
    Y SHOWN HERE, PRESS       <RETURN
> FOR THE FIRST QUESTION. REMEM- BER, YOU WILL GET A CHANCE TO SEE THE   E
    NTIRE PATHWAY AGAIN LATER.";A$
990  REM  QUESTIONS
1000  PRINT  CHR$ (25);V3$
1020  PRINT "1) CYCLIC  2) NON-CYCLIC  3) BOTH 1 & 2": PRINT
1030  PRINT "RESPOND TO EACH QUESTION BY ENTERING THENUMBER 1, 2 OR 3, DEP
    ENDING ON WHICH    CHOICE CORRECTLY ANSWERS THE QUESTION:"
1040  VTAB 9: PRINT  CHR$ (22): INPUT "WHICH PATHWAY PRODUCES NET ATP
? ";A$
1050  IF  VAL (A$) = 3 OR  LEFT$ (A$,1) = "B" THEN SC(1) = 1: PRINT : PRINT
    "YOUR ANSWER IS CORRECT!": GOSUB 2210: GOTO 1080
1060  PRINT : PRINT "YOUR ANSWER IS INCORRECT. BOTH THE      CYCLIC AND NO
    N-CYCLIC PATHWAYS PRODUCE  ATP. T
HIS RESULTS IN A NET GAIN OF ATP
  WHICH CAN BE USED IN THE DARK REACTIONS OF PHOTOSYNTHESIS OR IN OTHER SY
    NTHETIC"
1070  PRINT "PATHWAYS WHEN IN SURPLUS.": GOSUB 2210
1080  INPUT "WHICH PATHWAY INVOLVES PS II
? ";A$
1090  IF  VAL (A$) = 2 OR  LEFT$ (A$,1) = "N" THEN SC(1) = SC(1) + 1: PRINT
    : PRINT "YOU ARE CORRECT. THE CYCLIC PATHWAY ONLYINVOLVES PS I
.": GOSUB 2210: GOTO 1110
1100  PRINT : PRINT "YOU ARE INCORRECT. THE NON-CYCLIC IS THEONE WHICH INV
    OLVES PS II
 AS WELL AS     PS I.
 THE CYCLIC PATHWAY ONLY INVOLVES  PS I
.": GOSUB 2210
1110  INPUT "WHICH PATHWAY PRODUCES OXYGEN? ";A$
1120  IF  VAL (A$) = 2 OR  LEFT$ (A$,1) = "N" THEN SC(1) = SC(1) + 1: PRINT
    : PRINT "YOUR ANSWER IS CORRECT! WHEN LIGHT      STRIKES PS II
, A MOLECULE OF WATER      SPLITS AND RELEASES OXYGEN.": GOSUB 2210: GOTO
    1140
1130  PRINT : PRINT "SORRY, YOU ARE INCORRECT. SINCE THE NON-CYCLIC PATHWA
    Y IS THE ONE WHICH INVOLVESWATER, IT IS THE ONE THAT PRODUCES      OX
    YGEN WHEN A WATER MOLECULE SPLITS.": GOSUB 2210
1140  INPUT "WHICH PATHWAY TAKES PLACE ONLY IN THE   LIGHT? ";A$
1150  IF  VAL (A$) = 3 OR  LEFT$ (A$,1) = "B" THEN SC(1) = SC(1) + 1: PRINT
    : PRINT "YOU ARE RIGHT! ": GOSUB 2210: GOTO 1170
1160  PRINT : PRINT "YOU ARE NOT RIGHT. THE ENTIRE PROCESS OFPHOTOPHORPHOR
    YLATION REQUIRES LIGHT.    THEREFORE BOTH PATHWAYS REQUIRE LIGHT.  RE
    MEMBER HOW THE PATHWAY GOT ITS NAME.": GOSUB 2210
1170  INPUT "P1F330 IS THE REACTIVE CHLOROPHYLL        MOLECULE OF WHICH P
     ATHWAY? ";A$
1180  IF  VAL (A$) = 3 OR  LEFT$ (A$,1) = "B" THEN SC(1) = SC(1) + 1: PRINT
     : GOTO 1220
1190  PRINT : PRINT "SORRY, YOU ARE NOT CORRECT. YOU MUST    HAVE FORGOTTE
     N THAT P1F330 IS THE REACTIVEMOLECULE IN PS I
, AND PS I
IS INVOLVED  IN BOTH PATHWAYS. ALSO, DO NOT FORGET   THAT THE REACTIVE MOL
     ECULE IN EACH "
1200  PRINT "PIGMENT SYSTEM DOES NOT MAKE UP THE     ENTIRE PIGMENT SYSTEM
     . THERE ARE OTHER  PIGMENTS INVOLVED ALSO.": GOSUB 2210
1210  GOTO 1230
1220  PRINT "GOOD FOR YOU, YOU GOT THIS ONE RIGHT!   YOU MUST HAVE REMEMBE
     RED THAT P1F330 IS   THE REACTIVE MOLECULE IN PS I
, AND PS I
 IS INVOLVED IN BOTH PATHWAYS.": GOSUB 2210
1230  PRINT  CHR$ (25);V3$:SC = (SC(1) / 5) * 100: VTAB 4: PRINT "YOU CORR
     ECTLY ANSWERED ";SC(1);" OUT OF 5": PRINT "OF THESE QUESTIONS.": PRINT
     : PRINT "THIS GIVES YOU A PERCENTILE SCORE OF": PRINT SC;"%."
1235  PRINT : PRINT "KEEP THESE QUESTIONS IN MIND WHEN YOU   REVIEW THE SI
     MULATION OF THE ENTIRE     PHOTOPHOSPHORYLATION PATHWAY LATER ON."
1240  VTAB 22: INPUT "PRESS <RETURN
> FOR A WRITTEN SUMMARY OF PHOTOPHOSPHORYLATION.";A$
1250  REM  SUMMARY
1260  PRINT  CHR$ (25);V3$: PRINT "THE OUTSTANDING FEATURES OF CYCLIC AND
     NON-CYCLIC PHOTOPHOSPHORYLATION ARE     SUMMARIZED BELOW.": PRINT
1270  PRINT "NON-CYCLIC
:": PRINT "  1) INVOLVES PS I
 AND PS II
": PRINT "  2) PRODUCES ATP
 AND NADPH
": PRINT "  3) CAUSES WATER TO SPLIT AND RELEASE       OXYGEN.": PRINT
1280  PRINT "CYCLIC
:": PRINT "  1) INVOLVES PS I
 ONLY": PRINT "  2) PRODUCES ATP
, BUT NOT NADPH
": PRINT "  3) DOES NOT INVOLVE WATER, THEREFORE      OXYGEN IS NOT PRODU
     CED.": GOSUB 2210
1290  VTAB 3: PRINT "WELL, THAT SUMS UP PHOTOPHOSPHORYLATION.PRESS <RETURN

> FOR ANOTHER LOOK AT THE  SIMULATION OF THE ENTIRE PHOTOPHOS-     PHORYLA
     TION PATHWAY. HOPEFULLY IT WILL  HELP YOU PULL TOGETHER THE INFORMATI
     ON"
1295  PRINT "PRESENTED IN THIS MODULE."
1300  PRINT : INPUT "REMEMBER, MANY OF THE REACTIONS IN THESEPATHWAYS OCCU
     R SIMULATANEOUSLY IN THE   CHLOROPLASTS OF EACH PHOTOSYNTHETIC     CE
     LL, NOT ONE AT A TIME AS SHOWN IN THISPROGRAM.";A$
1310  PRINT V3$: PRINT "PLEASE BE PATIENT WHILE THE PROGRAM IS  LOADING...
     ": PRINT  CHR$ (4);"RUN PHOTOPHOS 4": END
1400  PRINT  CHR$ (25);V3$: PRINT "SINCE THIS IS A REVIEW FOR YOU, WOULD
     YOU LIKE TO": PRINT : PRINT "   1) TAKE THE QUIZ AGAIN": PRINT : PRINT
     "   2) GO ON TO THE SUMMARY"
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1405  PRINT : PRINT "OR 3) EXIT FROM THE PROGRAM"
1410  PRINT : INPUT "(1 OR 2)? ";A$
1420  IF  VAL (A$) = 1 THEN 1000
1430  IF  VAL (A$) = 2 THEN 1260
1440  IF  VAL (A$) = 3 THEN  PRINT V3$: PRINT "HOPE YOU ENJOYED THIS PROGR
    AM AND        BENEFITTED FROM IT.": PRINT "BYE FOR NOW.": END
1450  PRINT : INPUT "PLEASE RE-ENTER 1,2 OR 3...";A$: GOTO 1420
2000  REM  DRAW PATHWAY SUBROUTINE
2010  PRINT  CHR$ (25);V3$: HTAB (1): VTAB 12: PRINT  CHR$ (23);"ENERGY
"; CHR$ (25)
2020  PRINT  CHR$ (26); CHR$ (12)
2030  HTAB (1): VTAB 1: PRINT "HIGH": HTAB (8): PRINT "Z": HTAB (13): PRINT
    "FERREDOXIN": HTAB (1): VTAB 16: PRINT "LOW"
2040  VTAB 3: HTAB (12): PRINT ">": HPLOT 156,20 TO 181,20
2050  HPLOT 57,11 TO 79,19
2060  VTAB 2: HTAB (27): PRINT F$
2070  VTAB 4: HTAB (29): PRINT "NADP
+"
2080  FOR S = 2 TO 15 STEP 3: HTAB (3): VTAB S: PRINT "-": NEXT
2090  VTAB 13: HTAB (6): PRINT "P1F330+"
2100  VTAB 15: HTAB (6): PRINT "(PS I
)"
2110  VTAB 3: HTAB (8): PRINT "^"
2120  HPLOT 52,18 TO 52,92
2130  VTAB 9: HTAB (11): PRINT "CYT"
2140  VTAB 5: HTAB (14): PRINT E$
2150  VTAB 5: HTAB (16): PRINT "ADP
"
2160  VTAB 12: HTAB (9): PRINT "1L0"
2170  HPLOT 102,25 TO 79,63: HPLOT 73,73 TO 63,87
2180  HPLOT 0,133 TO 279,133
2190  VTAB 18: PRINT  CHR$ (22): RETURN
2200  REM  PAUSE & PRESS RETURN SUBROUTINES
2210  VTAB 24: INPUT "PRESS <RETURN
> TO CONTINUE";A$: PRINT V3$: RETURN
2220  FOR PAUSE = 1 TO 1200: NEXT : RETURN
2230  FOR PA = 1 TO 400: NEXT : RETURN
2240  FOR PA = 1 TO 180: NEXT : RETURN
2250  FOR PA = 1 TO 300: NEXT : RETURN
2260  FOR PA = 1 TO 100: NEXT : RETURN
```

```
100  GOTO 200
110  POKE 103,1
120  CALL 1002
130  CALL 6144
140  PRINT  CHR$ (16): INPUT "PLEASE DON'T PRESS <RESET
> DURING THIS  PROGRAM! PRESS <RETURN
> TO RESTART THIS PART OF THE PROGRAM.";A$
200  REM  THIS PROGRAM WAS DEVELOPED BY THE SUMIT I COURSEWARE DEVELOPMENT
       PROJECT, DEPARTMENT OF BIOLOGICAL SCIENCES, MICHIGAN TECHNOLOGICAL U
     NIVERSITY, HOUGHTON, MI 49931
210  REM  THIS MATERIAL IS BASED UPON WORK SUPPORTED BY THE NATIONAL SCIEN
     CE FOUNDATION UNDER GRANT NUMBER SED-7919051
220  REM  ANY OPINIONS, FINDINGS, AND CONCLUSIONS OR RECOMMENDATIONS EXPRE
     SSED IN THIS PUBLICATION ARE THOSE OF THE AUTHORS AND DO NOT NECESSAR
     ILY REFLECT THE VIEWS OF THE NATIONAL SCIENCE FOUNDATION
230  REM  SUBPROGRAM (PHOTOPHOS 4) OF PHOTOPHOSPHORYLATION
240  REM    BASED ON PUBLICATIONS BY STRYER (1981) AND LEHNINGER (1975)
250  REM    DESIGNED BY CATHERINE LEECE
260  REM   PROGRAMMED BY CATHERINE LEECE
270  REM  INTITIALIZE VARIABLES
280 V3$ =  CHR$ (16): PRINT V3$:CUE = 0
290  PRINT  CHR$ (12)
300 F$ = "
1ABEIJ0"
310 B$ = "1 GHKL   M0"
320 E$ = "1AJEIB0"
400  REM  MAIN PROGRAM ****
440  REM   MAIN PROGRAM/NON-CYCLIC PATHWAY
450  PRINT  CHR$ (26); CHR$ (12): GOSUB 1370
460  VTAB 23: HTAB (6): PRINT "** PRESS <ESC
> KEY TO STOP **"
470  VTAB 14: HTAB (17): PRINT "LIGHT
"
480  VTAB 17: HTAB (7): PRINT "H1000"
490  FOR Q = 1 TO 40
500  GOSUB 1950: IF  PEEK ( - 16384) = 155 THEN 1260
510  VTAB 17: HTAB (31): PRINT ">": HPLOT 150,108 TO 212,131: GOSUB 1950
520  VTAB 17: HTAB (32): PRINT "P10230": GOSUB 1950: HCOLOR= 0: HPLOT 150,
     108 TO 212,131: VTAB 17: HTAB (31): PRINT " ": GOSUB 1960
530  IF Q = 1 THEN  HPLOT 227,67 TO 227,123
540  HCOLOR= 3: VTAB 9: HTAB (33): PRINT " ": GOSUB 1960
550  FOR S = 16 TO 9 STEP  - 1: HTAB (32): VTAB S + 1: PRINT "     ": VTAB
     S: HTAB (32): PRINT "P10230": GOSUB 1980: NEXT
560  IF  PEEK ( - 16384) = 155 THEN 1260
570  VTAB 9: HTAB (32): PRINT "     ": VTAB 8: HTAB (35): PRINT "P10230"
580  VTAB 7: HTAB (36): PRINT "1D0": GOSUB 1960: VTAB 7: HTAB (36): PRINT
     " ": VTAB 6: HTAB (35): PRINT "1D0": GOSUB 1960: VTAB 6: HTAB (35): PRINT
     " "
590  VTAB 6: HTAB (34): PRINT "1D0": GOSUB 1960: VTAB 6: HTAB (34): PRINT
     " ": VTAB 7: HTAB (33): PRINT "1D0": HTAB (35): PRINT "P10230+": GOSUB
     1960: VTAB 8: HTAB (33): PRINT "Q"
600  IF  PEEK ( - 16384) = 155 THEN 1260
```

```
610  VTAB 8: HTAB (35): PRINT "      ": FOR S = 9 TO 17: VTAB S: HTAB (32):
      PRINT "P10230+": GOSUB 1980: IF S < 17 THEN  VTAB S: HTAB (32): PRINT
     "      ": NEXT
620  IF CUE = 2 THEN 670
630  SPEED= 150: VTAB 17: HTAB (7): PRINT "H1000 1JB0 21D0 + 1C00100 + 2H+
     ": SPEED= 255
640  GOSUB 1950
650  GOSUB 1960: VTAB 17: HTAB (7): PRINT "H1000"
660  GOSUB 1950
670  IF CUE = 2 THEN  VTAB 17: HTAB (15): PRINT " ":CUE = 0: GOTO 690
680  VTAB 17: HTAB (14): PRINT " "
690  VTAB 16: HTAB (15): PRINT "1D0": GOSUB 1960: IF  PEEK ( - 16384) = 15
     5 THEN 1260
700  GOSUB 1950
710  FOR S = 15 TO 35: VTAB 16: HTAB (S): PRINT " ": VTAB 16: HTAB (S + 1)
     : PRINT "1D0": GOSUB 1980: NEXT
720  GOSUB 1960: VTAB 16: HTAB (36): PRINT " ": HTAB (36): PRINT " "
730  VTAB 7: HTAB (33): PRINT " ": GOSUB 1980
740 V = 7: FOR S = 32 TO 11 STEP  - 1: HTAB (S): VTAB V: PRINT "1D0": GOSUB
     1980: IF S <  > 11 THEN  HTAB (S): VTAB V: PRINT " "
750  IF  PEEK ( - 16384) = 155 THEN 1260
760  IF S < 31 THEN V = 8: IF S < 27 THEN V = 9: IF S < 22 THEN V = 10: IF
     S < 17 THEN V = 11: IF S < 13 THEN V = 12
770  NEXT
780  GOSUB 1960
790  VTAB 12: HTAB (11): PRINT " ": HTAB (10): PRINT " ": VTAB 8: HTAB (33
     ): PRINT "Q"
800  GOSUB 1950
810  VTAB 12: HTAB (28): PRINT "ADP
": GOSUB 1950: GOSUB 1950: VTAB 12: HTAB (22): PRINT "ATP
"; TAB( 28);"   "
820  GOSUB 1950: FOR S = 22 TO 37: VTAB 12: HTAB (S): PRINT " ATP
": GOSUB 1980: NEXT
830  VTAB 12: HTAB (38): PRINT " AT
": GOSUB 1980: VTAB 12: HTAB (39): PRINT " A
": GOSUB 1980: VTAB 12: HTAB (40): PRINT " ": GOSUB 1940
840  IF  PEEK ( - 16384) = 155 THEN 1260
850  VTAB 12: HTAB (40): PRINT "A": GOSUB 1980: VTAB 12: HTAB (39): PRINT
     "AD
": GOSUB 1980: VTAB 12: HTAB (38): PRINT "ADP
": GOSUB 1980
860  FOR S = 37 TO 28 STEP  - 1: VTAB 12: HTAB (S): PRINT "ADP
 ": GOSUB 1980: NEXT
870  HPLOT 108,106 TO 75,99
880  GOSUB 1950: VTAB 13: HTAB (6): PRINT "P1F330": GOSUB 1950: HCOLOR= 0:
      HPLOT 108,106 TO 75,99: GOSUB 1960
890  IF Q = 1 THEN  HPLOT 52,18 TO 52,95: VTAB 3: HTAB (8): PRINT " "
900  HCOLOR= 3: VTAB 13: HTAB (5): PRINT "P1F330 "
910  IF  PEEK ( - 16384) = 155 THEN 1260
920  HTAB (11): VTAB 12: PRINT " "
930  FOR S = 13 TO 3 STEP  - 1: HTAB (5): VTAB S + 1: PRINT "      ": VTAB S
     : HTAB (5): PRINT "P1F330": GOSUB 1980: NEXT
```

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940  VTAB 3: HTAB (3): PRINT "P1F330  ": GOSUB 1950
950  VTAB 2: HTAB (6): PRINT "1D0": GOSUB 1970: VTAB 2: HTAB (6): PRINT "
     ": VTAB 1: HTAB (7): PRINT "1D0": GOSUB 1970: VTAB 1: HTAB (7): PRINT
     " ": HTAB (8): VTAB 1: PRINT "1D0"
960  HTAB (8): PRINT "Z": VTAB 3: HTAB (3): PRINT "P1F330+"
970  GOSUB 1950: IF  PEEK ( - 16384) = 155 THEN 1260
980  VTAB 3: HTAB (3): PRINT "       ": VTAB 3: HTAB (4): PRINT "P1F330+"
990  FOR S = 3 TO 12: HTAB (4): VTAB S: PRINT "       ": HTAB (4): PRINT "P
     1F330+": GOSUB 1980: NEXT
1000  VTAB 13: HTAB (4). PRINT "  P1F330+"
1010  FOR S = 8 TO 12: VTAB 1: HTAB (S): PRINT " ": VTAB 1: HTAB (S + 1): PRINT
     "1D0": GOSUB 1980: NEXT
1020  VTAB 1: HTAB (13): PRINT " ": VTAB 2: HTAB (8): PRINT "Z": VTAB 2: HTAB
     (14): PRINT "1D0": HTAB (14): PRINT "FERREDOXIN"
1030  IF  PEEK ( - 16384) = 155 THEN 1260
1040  IF CUE = 3 THEN CUE = 0: GOTO 1640
1050  IF  INT (Q / 2) <  > Q / 2 THEN CUE = 2: VTAB 2: HTAB (14): PRINT "
     "; TAB( 16);"1D100": GOTO 1240
1060  VTAB 16: HTAB (26): PRINT "H+": HTAB (25): PRINT " ": VTAB 15: HTAB
     (26): PRINT "H+": HTAB (26): PRINT "  "
1070  FOR S = 26 TO 34: HTAB (S): VTAB 15: PRINT " H+": GOSUB 1980: NEXT
1080  FOR S = 15 TO 5 STEP  - 1: HTAB (35): VTAB S: PRINT "  ": HTAB (35):
      VTAB S - 1: PRINT "H+": GOSUB 1980: NEXT
1090  VTAB 17: HTAB (11): PRINT "                    "
1100  FOR S = 14 TO 21: VTAB 2: HTAB (S): PRINT "  1D D0": GOSUB 1980: NEXT

1110  IF  PEEK ( - 16384) = 155 THEN 1260
1120  VTAB 2: HTAB (23): PRINT " ": VTAB 5: HTAB (25): PRINT "1D0": GOSUB
     1980: VTAB 2: HTAB (25): PRINT " ": VTAB 5: HTAB (27): PRINT "1D0": GOSUB
     1980
1130  FOR S = 25 TO 29: VTAB 5: HTAB (S): PRINT "  1D D0": GOSUB 1970: NEXT

1140  VTAB 5: HTAB (33): PRINT " ": VTAB 1: HTAB (13): PRINT "           ":
      GOSUB 1960: VTAB 5: HTAB (31): PRINT "  1D0": VTAB 5: HTAB (33): PRINT
     " ": VTAB 3: HTAB (14): PRINT "FERREDOXIN"
1150  VTAB 4: HTAB (29): PRINT "NADP H
  ": GOSUB 1950: GOSUB 1950: VTAB 2: HTAB (29): PRINT "NADPH
": VTAB [illegible]: HTAB (29): PRINT "      "
1160  IF  PEEK ( - 16384) = 155 THEN 1260
1170  GOSUB 1960: FOR S = 29 TO 35: VTAB 2: HTAB (S): PRINT " NADPH

": GOSUB 1980: NEXT
1180  VTAB 2: HTAB (36): PRINT " NADP
": GOSUB 1980: VTAB 2: HTAB (37): PRINT " NAD
": GOSUB 1980: VTAB 2: HTAB (38): PRINT " NA
": GOSUB 1980: VTAB 2: HTAB (39): PRINT " N": GOSUB 1980
1190  VTAB 2: HTAB (40): PRINT " ": GOSUB 1940
1200  IF (Q / 2) / 2 <  >  INT ((Q / 2) / 2) THEN CUE = 3: VTAB 3: HTAB (1
     3): PRINT " ": GOTO 1230
1210  VTAB 4: HTAB (40): PRINT "N": GOSUB 1980: VTAB 4: HTAB (39): PRINT "
     NA
": GOSUB 1980: VTAB 4: HTAB (38): PRINT "NAD
": GOSUB 1980: VTAB 4: HTAB (37): PRINT "NADP
": GOSUB 1980: VTAB 4: HTAB (36): PRINT "NADP
+": GOSUB 1980
1220  FOR S = 35 TO 29 STEP  - 1: VTAB 4: HTAB (S): PRINT "NADP+
 ": GOSUB 1980: NEXT
1230  IF  PEEK ( - 16384) = 155 THEN 1260
1240  NEXT Q
1250  REM   END SIMULATION
1260  POKE  - 16368,0: VTAB 14: HTAB (17): PRINT "LIGHT
": GOSUB 1940
1270  VTAB 23: PRINT  CHR$ (5): VTAB 23: INPUT "PRESS <RETURN
> WHEN YOU ARE THROUGH     EXAMINING THIS DIAGRAM";A$
1280  PRINT  CHR$ (25);V3$: PRINT "NOW THAT YOU HAVE EXAMINED THE COM-
      PONENTS OF PHOTOPHOSPHORYLATION, AND    REVIEWED THE SIMULATION OF T
     HE ENTIRE   PATHWAY, THE SIMULATION OF PHOTO-       SYNTHETIC PRODUCT
     S BEING FORMED AND"
1290  PRINT "USED SHOULD MAKE MORE SENSE.": PRINT : INPUT "PRESS <RETURN
> TO REVIEW THE SIMULATION OF PHOTOSYNTHESIS. AFTERWARDS YOU MAY   EXIT TH
     E PROGRAM OR REVIEW ANY OF ITS   SECTIONS.";A$
1300  PRINT V3$: PRINT "PLEASE BE PATIENT WHILE THE PROGRAM IS  LOADING...
     ": PRINT  CHR$ (4);"RUN PHOTOPHOS 5": END
1360  REM  DRAW PATHWAY SUBROUTINE
1370  PRINT  CHR$ (25);V3$: HCOLOR= 3: HTAB (1): VTAB 12: PRINT  CHR$ (23)
     ;"ENERGY
"; CHR$ (25)
1380  HTAB (1): VTAB 1: PRINT "HIGH": HTAB (8): PRINT "Z": HTAB (13): PRINT
     "2FERREDOXIN": HTAB (1): VTAB 17: PRINT "LOW"
1390  VTAB 3: HTAB (12): PRINT ">": HPLOT 162,20 TO 181,20
1400  HPLOT 57,11 TO 79,19
1410  VTAB 2: HTAB (27): PRINT F$
1420  VTAB 4: HTAB (29): PRINT "NADP
+"
1430  FOR S = 2 TO 15 STEP 3: HTAB (3): VTAB S: PRINT "-": NEXT
1440  HTAB (33): VTAB 8: PRINT "Q"
1450  VTAB 17: HTAB (32): PRINT "P10230"
1460  VTAB 13: HTAB (6): PRINT "P1F330+"
1470  VTAB 3: HTAB (8): PRINT "^"
1480  HPLOT 52,18 TO 52,92
1490  VTAB 9: HTAB (33): PRINT "^"
1500  HPLOT 227,67 TO 227,123
1510  VTAB 11: HTAB (19): PRINT "CYT"
1520  VTAB 13: HTAB (11): PRINT "<"
1530  VTAB 10: HTAB (24): PRINT B$
1540  HPLOT 221,62 TO 147,80: HPLOT 123,86 TO 72,100
1550  VTAB 9: HTAB (11): PRINT "CYT"
1560  VTAB 12: HTAB (28): PRINT "ADP
"

1570  VTAB 5: HTAB (14): PRINT E$
1580  VTAB 5: HTAB (16): PRINT "ADP
"

1590  VTAB 12: HTAB (9): PRINT "1L0"
1600  HPLOT 102,25 TO 79,63: HPLOT 73,73 TO 63,87
```

```
1610  HPLOT 0,170 TO 279,170
1620  VTAB 19: PRINT  CHR$ (22): RETURN
1630  REM  CYCLIC PATHWAY
1640  FOR R = 1 TO 2: VTAB 2: HTAB (14): PRINT " ":H = 14
1650  IF  PEEK ( - 16384) = 155 THEN 1260
1660  FOR S = 4 TO 11: VTAB S: HTAB (H): PRINT "1D0": GOSUB 1980: VTAB S: HTAB
     (H): PRINT " "
1670  IF S < 7 THEN H = H - 1: GOTO 1690
1680  IF S > 7 AND S < 10 THEN H = H - 1: GOTO 1690
1690  NEXT
1700  VTAB 12: HTAB (10): PRINT "1D0": GOSUB 1960: VTAB 12: HTAB (10): PRINT
     " ": HTAB (10): PRINT " "
1710  VTAB 3: HTAB (14): PRINT "FERREDOXIN": VTAB 5: HTAB (16): PRINT "ADP

": GOSUB 1950: GOSUB 1950: VTAB 7: HTAB (16): PRINT "ATP
": VTAB 5: HTAB (16): PRINT "    "
1720  GOSUB 1950: FOR S = 16 TO 37: VTAB 7: HTAB (S): PRINT " ATP
": GOSUB 1980: NEXT
1730  IF  PEEK ( - 16384) = 155 THEN 1260
1740  VTAB 7: HTAB (38): PRINT " AT
": GOSUB 1980: VTAB 7: HTAB (39): PRINT " A": GOSUB 1980: VTAB 7: HTAB (40
     ): PRINT " ": GOSUB 1940
1750  VTAB 5: HTAB (40): PRINT "A": GOSUB 1980: VTAB 5: HTAB (39): PRINT "
     AD
": GOSUB 1980: VTAB 5: HTAB (38): PRINT "ADP
": GOSUB 1980
1760  FOR S = 37 TO 16 STEP  - 1: VTAB 5: HTAB (S): PRINT "ADP
 ": GOSUB 1980: NEXT
1770  IF  PEEK ( - 16384) = 155 THEN 1260
1780  HPLOT 108,106 TO 75,99: GOSUB 1950: VTAB 13: HTAB (6): PRINT "P1F33
     0": GOSUB 1950: HCOLOR= 0: HPLOT 108,106 TO 75,99: GOSUB 1960
1790  HCOLOR= 3: VTAB 13: HTAB (5): PRINT "P1F330 "
1800  HTAB (11): VTAB 12: PRINT " "
1810  FOR S = 13 TO 3 STEP  - 1: HTAB (5): VTAB S + 1: PRINT "      ": VTAB
     S: HTAB (5): PRINT "P1F330": GOSUB 1980: NEXT
1820  VTAB 3: HTAB (3): PRINT "P1F330  ": GOSUB 1950
1830  VTAB 2: HTAB (6): PRINT "1D0": GOSUB 1970: VTAB 2: HTAB (6): PRINT "
     ": VTAB 1: HTAB (7): PRINT "1D0": GOSUB 1970: VTAB 1: HTAB (7): PRINT
     " ": HTAB (8): VTAB 1: PRINT "1D0"
1840  GOSUB 1950: IF  PEEK ( - 16384) = 155 THEN 1260
1850  VTAB 3: HTAB (3): PRINT "       ": VTAB 3: HTAB (4): PRINT "P1F330+"
1860  FOR S = 3 TO 12: HTAB (4): VTAB S: PRINT "       ": HTAB (4): PRINT "
     P1F330+": GOSUB 1980: NEXT
1870  VTAB 13: HTAB (4): PRINT "  P1F330+"
1880  FOR S = 8 TO 12: VTAB 1: HTAB (S): PRINT " ": VTAB 1: HTAB (S + 1): PRINT
     "1D0": GOSUB 1980: NEXT
1890  VTAB 1: HTAB (13): PRINT " ": VTAB 2: HTAB (8): PRINT "Z": VTAB 2: HTAB
     (14): PRINT "1D0": HTAB (14): PRINT "FERREDOXIN"
1900  GOSUB 1950
1910  NEXT : VTAB 3: HTAB (13): PRINT "2"
1920  VTAB 2: HTAB (14): PRINT " "; TAB( 16): PRINT "1D0": GOTO 1210
1930  REM   PAUSE SUBROUTINES
```

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1940  FOR PAUSE = 1 TO 1200: NEXT : RETURN
1950  FOR PA = 1 TO 200: NEXT : RETURN
1960  FOR PA = 1 TO 150: NEXT : RETURN
1970  FOR PA = 1 TO 80: NEXT : RETURN
1980  FOR PA = 1 TO 55: NEXT : RETURN
```

```
100  GOTO 200
110  POKE 103,1
120  CALL 1002
130  CALL 6144
140  PRINT  CHR$ (16): INPUT "PLEASE DON'T PRESS <RESET
> DURING THIS  PROGRAM! PRESS <RETURN
> TO RESTART THIS PART OF THE PROGRAM.";A$
200  REM  THIS PROGRAM HAS DEVELOPED BY THE SUMIT I COURSEWARE DEVELOPMENT
       PROJECT, DEPARTMENT OF BIOLOGICAL SCIENCES, MICHIGAN TECHNOLOGICAL U
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230  REM     SUBPROGRAM (PHOTOPHOS 5) OF PHOTOPHOSPHORYLATION
240  REM    BASED ON PUBLICATIONS BY STRYER (1981) AND LEHNINGER (1975)
250  REM    DESIGNED BY CATHERINE LEECE
260  REM   PROGRAMMED BY CATHERINE LEECE
270  REM  INTITIALIZE VARIABLES
280 V3$ =  CHR$ (16): PRINT V3$
290  PRINT  CHR$ (12)
1310  PRINT V3$
1320  VTAB 23: HTAB (6): PRINT "** PRESS <ESC
> KEY TO STOP **"
1330  VTAB 20: PRINT  CHR$ (22)
1340  HPLOT 39,30 TO 39,105 TO 99,105 TO 99,30 TO 39,30: HPLOT 179,30 TO 1
     79,105 TO 239,105 TO 239,30 TO 179,30
1350  VTAB 8: HTAB (8): PRINT "LIGHT": HTAB (7): PRINT "REACTION": VTAB 8:
      HTAB (29): PRINT "DARK": HTAB (27): PRINT "REACTION"
1360  VTAB 1: HTAB (8): PRINT "LIGHT
": VTAB 16: HTAB (1): PRINT "H100O"
1370  FOR U = 1 TO 20
1380  GOSUB 2230: FOR S = 1 TO 2
1390  HPLOT 66,8 TO 66,29 TO 70,24: HPLOT 62,24 TO 66,29
1400  GOSUB 2230
1410  VTAB 16: HTAB (1): PRINT "H100O"
1420  VTAB 16: HTAB (5): SPEED= 150: PRINT "1JB0 21D 0+ 2H+ + 1C0O1O0"
1430  GOSUB 2230
1440  VTAB 16: HTAB (1): PRINT "H100O"
1450  HCOLOR= 0: HPLOT 66,8 TO 66,29 TO 70,24: HPLOT 62,24 TO 66,29: HCOLOR=
     3
1460  SPEED= 255: VTAB 15: HTAB (9): PRINT "1D0": HTAB (8): PRINT " ": GOSUB
     2260: VTAB 15: HTAB (9): PRINT " ": VTAB 13: HTAB (9): PRINT "1D0"
1470  GOSUB 2250: VTAB 13: HTAB (9): PRINT " "
1480  GOSUB 2230: VTAB 16: HTAB (9): PRINT " ": VTAB 15: HTAB (9): PRINT "
     1
D0": GOSUB 2260: VTAB 15: HTAB (9): PRINT " ": VTAB 13: HTAB (9): PRINT "
     1D0": GOSUB 2250: VTAB 13: HTAB (9): PRINT " "
1490  IF  PEEK ( - 16384) = 155 THEN 1900
1500  GOSUB 2230: VTAB 15: HTAB (13): PRINT "H+": HTAB (13): PRINT " ": GOSUB
     2260: VTAB 15: HTAB (13): PRINT "  ": VTAB 13: HTAB (13): PRINT "H+":
```

```
     GOSUB 2250: VTAB 13: HTAB (13): PRINT "  "
1510  GOSUB 2230: VTAB 16: HTAB (14): PRINT "  ": VTAB 15: HTAB (13): PRINT
     "H+": GOSUB 2260: VTAB 15: HTAB (13): PRINT "  ": VTAB 13: HTAB (13):
     PRINT "H+": GOSUB 2250: VTAB 13: HTAB (13): PRINT "  "
1520  GOSUB 2230: IF  PEEK ( - 16384) = 155 THEN 1900
1530  NEXT S
1540  VTAB 16: HTAB (5): PRINT "                  "
1550  VTAB 6: HTAB (26): PRINT ">": HPLOT 100,43 TO 181,43
1560  FOR Q = 1 TO 3
1570  VTAB 5: HTAB (16): PRINT "P": GOSUB 2260: VTAB 5: HTAB (16): PRINT "
     TP
": GOSUB 2260: VTAB 5: HTAB (16): PRINT "ATP
": GOSUB 2260
1580  FOR S = 16 TO 22: VTAB 5: HTAB (S): PRINT " ATP
": GOSUB 2260: NEXT : VTAB 5: HTAB (23): PRINT " AT
": GOSUB 2260: VTAB 5: HTAB (24): PRINT " A": GOSUB 2260: VTAB 5: HTAB (25
     ): PRINT " "
1590  IF  PEEK ( - 16384) = 155 THEN 1900
1600  NEXT Q: VTAB 11: HTAB (26): PRINT ">": HPLOT 100,83 TO 181,83
1610  FOR T = 1 TO 2: VTAB 10: HTAB (16): PRINT "H": GOSUB 2260: VTAB 10: HTAB
     (16): PRINT "PH
": GOSUB 2260: VTAB 10: HTAB (16): PRINT "DPH
": GOSUB 2260: VTAB 10: HTAB (16): PRINT "ADPH
": GOSUB 2260: VTAB 10: HTAB (16): PRINT "NADPH

1620  GOSUB 2260
1630  FOR S = 16 TO 20: VTAB 10: HTAB (S): PRINT " NADPH
": GOSUB 2260: NEXT : VTAB 10: HTAB (21): PRINT " NADP
": GOSUB 2260: VTAB 10: HTAB (22): PRINT " NAD
": GOSUB 2260: VTAB 10: HTAB (23): PRINT " NA
"
1640  GOSUB 2260: VTAB 10: HTAB (24): PRINT " N
1650  GOSUB 2260: VTAB 10: HTAB (25): PRINT " ": GOSUB 2260: IF  PEEK ( -
     16384) = 155 THEN 1900
1660  NEXT T
1670  HCOLOR= 0: HPLOT 100,43 TO 181,43: HTAB (26): VTAB 6: PRINT " ": HPLOT
     100,83 TO 181,83: HCOLOR= 3: HTAB (26): VTAB 11: PRINT " ": HPLOT 179
     ,30 TO 179,105
1680  GOSUB 2230
1690  HPLOT 242,0 TO 221,29: HPLOT 170,0 TO 192,29: FOR S = 1 TO 4: HTAB (
     29): VTAB (S): PRINT "CO100": IF S = 1 THEN  GOSUB 2230: GOTO 1710
1700  GOSUB 2260
1710  HTAB (29): VTAB (S): PRINT "     ": NEXT : HPLOT 179,30 TO 239,30
1720  HCOLOR= 0: HPLOT 242,0 TO 221,29: HPLOT 170,0 TO 192,29: HCOLOR= 3
1730  GOSUB 2230: VTAB 6: HTAB (15): PRINT "<": HPLOT 97,43 TO 178,43
1740  FOR Q = 1 TO 3: VTAB 5: HTAB (25): PRINT "A": GOSUB 2260: VTAB 5: HTAB
     (24): PRINT "AD": GOSUB 2260: VTAB 5: HTAB (23): PRINT "ADP
": GOSUB 2260
1750  FOR S = 22 TO 16 STEP  - 1: VTAB 5: HTAB (S): PRINT "ADP

 ": GOSUB 2260: NEXT : VTAB 5: HTAB (16): PRINT "DP
 ": GOSUB 2260: VTAB 5: HTAB (16): PRINT "P ": GOSUB 2260: VTAB 5: HTAB (1
    6): PRINT " "
1760  IF  PEEK ( - 16384) = 155 THEN 1900
1770  NEXT Q: GOSUB 2230
1780  HTAB (15): VTAB 11: PRINT "<": HPLOT 97,83 TO 178,83
1790  FOR Q = 1 TO 2
1800  VTAB 10: HTAB (25): PRINT "N
": GOSUB 2260: VTAB 10: HTAB (24): PRINT "NA
": GOSUB 2260: VTAB 10: HTAB (23): PRINT "NAD
": GOSUB 2260: VTAB 10: HTAB (22): PRINT "NADP
": GOSUB 2260: VTAB 10: HTAB (21): PRINT "NADP
+": GOSUB 2260
1810  FOR S = 20 TO 16 STEP  - 1: VTAB 10: HTAB (S): PRINT "NADP
+ ": GOSUB 2260: NEXT : VTAB 10: HTAB (16): PRINT "ADP
+ ": GOSUB 2260: VTAB 10: HTAB (16): PRINT "DP
+ ": GOSUB 2260: VTAB 10: HTAB (16): PRINT "P+ ": GOSUB 2260: VTAB 10: HTAB
    (16): PRINT "+ "
1820  GOSUB 2260: VTAB 10: HTAB (16): PRINT " "
1830  GOSUB 2260: IF  PEEK ( - 16384) = 155 THEN 1900
1840  NEXT Q
1850  HCOLOR= 0: HPLOT 97,43 TO 178,43: HPLOT 97,83 TO 178,83: HCOLOR= 3: VTAB
    6: HTAB (15): PRINT " ": VTAB 11: HTAB (15): PRINT " ": HPLOT 99,30 TO
    99,105
1860  HPLOT 208,106 TO 208,125 TO 212,120: HPLOT 208,125 TO 204,120: VTAB
    17: HTAB (27): PRINT "SUGAR OR": HTAB (28): PRINT "STARCH": GOSUB 222
    0
1865  GOSUB 2220
1870  HCOLOR= 0: HPLOT 208,106 TO 208,125 TO 212,120: HPLOT 208,125 TO 204
    ,120: HCOLOR= 3: VTAB 17: HTAB (27): PRINT "        ": HTAB (28): PRINT
    "      ": GOSUB 2230
1880  IF  PEEK ( - 16384) = 155 THEN 1900
1890  NEXT U
1900  POKE  - 16368,0: VTAB 1: HTAB (8): PRINT "LIGHT
"
1905  VTAB 22: PRINT  CHR$ (6): VTAB 23: INPUT "PRESS <RETURN
> FOR THE PROGRAM MENU";A$: PRINT  CHR$ (25);V3$
1910  REM  MENU
1915  PRINT "YOU HAVE REACHED THE END OF THIS PROGRAMON PHOTOPHOSPHORYLATI
    ON.
1920  PRINT : PRINT "WOULD YOU LIKE TO": PRINT : PRINT "   1) REVIEW THE C
    YCLIC PATHWAY": PRINT : PRINT "   2) REVIEW THE NON-CYCLIC PATHWAY": PRINT

1930  PRINT "   3) REVIEW THE SIMULATION OF THE            PHOTOPHOSPHORYL
    ATION PATHWAY": PRINT : PRINT "   4) REVIEW THE SIMULATION OF PHOTO-
            SYNTHESIS": PRINT : PRINT "OR 5) EXIT FROM THE PROGRAM
1940  PRINT : PRINT "(BE SURE TO REVIEW ANY SECTION YOU DID  NOT UNDERSTAN
    D!)": PRINT : INPUT A$
1950  IF  VAL (A$) = 2 THEN  PRINT V3$: PRINT "PLEASE BE PATIENT WHILE THE
    PROGRAM IS  LOADING...": PRINT  CHR$ (4);"RUN PHOTOPHOS 2": END
1960  IF  VAL (A$) = 4 THEN 280
1970  IF  VAL (A$) = 3 THEN  PRINT V3$: PRINT "PLEASE BE PATIENT WHILE THE
    PROGRAM IS  LOADING...": PRINT  CHR$ (4);"RUN PHOTOPHOS 4": END
1975  IF  VAL (A$) = 1 THEN  PRINT V3$: PRINT "PLEASE BE PATIENT WHILE THE
```

```
    PROGRAM IS  LOADING...": PRINT  CHR$ (4);"RUN PHOTOPHOS 3": END
1980  IF  VAL (A$) <  > 5 THEN  PRINT : INPUT "PLEASE RE-ENTER-";A$: GOTO
    1950
1990  PRINT V3$: PRINT "THANK YOU FOR RUNNING THIS PROGRAM.     HOPE IT HE
    LPED YOU!": END
2200  REM  PAUSE & PRESS RETURN SUBROUTINES
2210  VTAB 24: INPUT "PRESS <RETURN
> TO CONTINUE";A$: PRINT V3$: RETURN
2220  FOR PA = 1 TO 1200: NEXT : RETURN
2230  FOR PA = 1 TO 400: NEXT : RETURN
2240  FOR PA = 1 TO 180: NEXT : RETURN
2250  FOR PA = 1 TO 300: NEXT : RETURN
2260  FOR PA = 1 TO 100: NEXT : RETURN
```

Appendix C

Photophosphorylation
User's Guide

The User's Guide presents background information, applications, suggested exercises and documentation for the Photophosphorylation program.

Abstract

This program presents an introduction to the light reactions of photosynthesis, photophosphorylation. After an introduction, the complete pathway is presented to provide an overview and foundation from which to progress. The pathway is then broken into its cyclic and non-cyclic components, and each is discussed step by step at the molecular level. The program leads the user along the pathways taken by an electron which has become excited by light energy. The program also stresses the importance of the products of the light reactions to the dark reactions of photosynthesis. Several questions are presented throughout the program to test the user's understanding of the concepts and to create an interactive program.

Prerequisite: Basic understanding of molecules and atoms.

Objectives: The user will be able to:

Distinguish between cyclic and non-cyclic photophosphorylation and explain the conditions necessary for each to occur.

Explain the basic difference between an electron donor and electron acceptor at the molecular level.

Explain the roles played by light and pigments in photophosphorylation.

Background Information

Photosynthesis is the conversion of light energy to chemical energy within a plant. The reactins involved take place in two stages, the light and dark reactions. The light reactions depend on photosynthetic pigments to convert light energy to ATP and NADPH. These products are then used in the dark reactions to convert carbon dioxide to carbohydrates. The dark reactions can occur in either light or dark conditions because they do not rely on pigments. However the light reactions, also termed photophosphorylation, depend on pigments to absorb light, thus initiating the reactions involved.

The photosynthetic cells of a plant, such as leaf cells, contain organelles called chloroplast(id)s. A chloroplast is surrounded by a single membrane; an inner membrane is folded to form many flattened vesicles called thykaloid disks. These disks occur in stacks called grana on which the light reactions of photosynthesis occur; the grana contain all of the pigments and enzymes necessary for the reactions. The dark reactions occur in the stroma or liquid phase of the chloroplast. Most chloroplasts contain the pigment chlorophyll, as well as the two classes of accessory pigments, carotenoids and phycobilins (Lehninger, 1975). All oxygen producing photosynthetic cells of higher plants contain two types of chlorophyll, chlorophyll a and chlorophyll b, c or d depending on the type of plant.

A pigment is a molecule which can absorb light because of its molecular structure, particularly the arrangement of electrons associated with the double bonds. When light strikes a pigment molecule capable of absorbing light of a given wavelength, light energy is absorbed by some of the electrons which are boosted to a higher energy level; the molecule thus becomes excited (Lehninger, 1975).

In 1937 R. Hill provided the first experimental evidence that the absorption of light energy causes electron flow (Lehninger, 1975). When he exposed a solution of cell-free preparations obtained from photosynthetic organisms (intact chloroplasts), water, and an electron acceptor to light, he found that oxygen was produced and the acceptor molecules were reduced. Light energy caused certain chlorophyll molecules to become excited and lose an electron to an acceptor molecule; then water split to lose an electron to chlorophyll to fill the "electron hole," simultaneously releasing oxygen. This discovery (called the Hill Reaction) formed the basis of the photophosphorylation pathway, and gradually each of the electron donors and acceptors was discovered to yield the pathway we know today.

Applications

This program is best suited for an introductory college level general biology or botany class. It may also be useful review for a basic biochemistry or plant physiology course. Due to the large amount of material presented in the program, it is suggested that the user should be exposed to the subject prior to running the program. That is, either through a lecture introducing the topic or through an introductory text such as Biology of Plants by Raven, Evert and Curtis (1976). For the more advanced user, Lehninger's Short Course in Biochemistry or Bidwell's Plant Physiology would suffice. If a more advanced look at photophosphorylation is desired after running the program, Stryer's Biochemistry (1981) provides an up to date, detailed coverage of the topic. A laboratory exercise dealing with the Hill Reaction is presented in the Appendix; it is suggested that such an exercise be used as a supplement to this program in a laboratory situation.

Suggested Exercises

1. Explain why the two phases of photophosphorylation are termed cyclic and non-cyclic. What makes them different? What are their products? What conditions are necessary for the cyclic pathway to operate?

2. Explain the difference between Pigment Systems I and II. Where do they fit into the light reactions?

3. Explain how light is related to the release of oxygen from a plant at the molecular level.

The Program

This program operates in a special graphics mode called the High Resolution Character Generator (HRCG). This allows the HGR screen to operate as both a graphics and a text screen. Since pressing the RESET key interferes with the proper functioning of this mode, it is suggested that the user press the CTRL and C keys simultaneously if (s)he wishes to break the program. For more information about HRCG refer to the Applesoft Tool-Kit Manual (Apple Computer Co., 1980).

In all subprograms:

LINE NUMBERS	FUNCTION
100-140	RESET error message
200-260	Remarks

Subprogram: PHOTOPHOS 1

LINE NUMBERS	FUNCTION
270-290	Initialize variables
300-550	Main program (Introduction)
560-1170	Photosynthesis simulation subroutine
1180-1240	Pause subroutines

Subprogram: PHOTOPHOS 1.5

LINE NUMBERS	FUNCTION
270-320	Initialize variables
400-1200	Main program (Non-cyclic pathway)
1210-1270	Menu
1280-1540	Subroutine which draws basic pathway
1440-1840	Subroutine which simulates cyclic pathway
1850-1900	Pause subroutines

Subprogram: PHOTOPHOS 2

LINE NUMBERS	FUNCTION
270-320	Initialize variables
400-1650	Main program (Non-cyclic pathway)
1660-1730	Menu
1740-1950	Subroutine which draws basic pathway
1960-2010	Pause subroutines

Subprogram: PHOTOPHOS 3

LINE NUMBERS	FUNCTION
270-320	Initialize variables
400-1990	Main program (Cyclic pathway)
990-1240	Quiz questions
1250-1450	Summary
2000-2190	Subroutine which draws basic pathway
2210-2260	Pause subroutines

Subprogram: PHOTOPHOS 4

LINE NUMBERS	FUNCTION
270-320	Initialize variables
400-1920	Main program (Simulation of entire pathway)
1930-1980	Pause subroutines

LINE NUMBERS	FUNCTION
Subprogram:	PHOTOPHOS 5
270-290	Initialize variables
1310-1950	Main program (Simulation of photosynthesis)
1910-1990	Menu
2200-2260	Pause subroutines

Glossary for Photophosphorylation Subprograms

A$ - Holds input from keyboard
B$ - Holds arrow shape
CUE - Flag used in printing pathways
E$ - Holds arrow shape
F$ - Holds arrow shape
FLAG - Flag for counting wrong answers
H - Htab counter
PA(USE) - Pause loop counter
Q - Loop counter
R - Loop counter
S - Loop counter
SC - Holds raw score out of 5 quiz questions
SC(- Holds percentile score for quiz
T - Loop counter
U - Loop counter
V - Vtab counter
V3$ - CHR$(16) - Clears screen and homes cursor*

*Function of HRCG (see Apple Computer Co., 1980)

Appendix

Laboratory Exercise: The Hill Reaction

To be used in conjunction with the Photophosphorylation program.

Note: It is important to keep the temperatures low; after the chloroplasts have been isolated, be certain that all test tube samples are kept immersed in an ice water bath.

Remove the midribs from the spinach leaves provided; weigh out 50g of leaves and homogenize them with 50ml isolation medium (0.4M sucrose in 0.06M potasium phosphate buffer, pH 6.5) in a blender for 2 minutes. Filter the green suspension through several layers of cheesecloth and then centrifuge the supernatant for 2 minutes at 600g. Remove the supernatant and centrifuge it for 10 minutes at 100g. Wash the precipitate (chloroplasts) by resuspending in a small volume of the isolation medium and centrifuge again under the same conditions. Finally, suspend the pellet in 20ml of the cold reaction medium (0.03M potassium phosphate buffer, pH 6.5, with 0.01M potassium chloride) by gently agitating with a glass stirring rod.

Dilute the original chloroplast suspension (with reaction medium) to give a chlorophyll concentration of 5mg/ml. Using 3 cuvettes, add 1ml of the chloroplast suspension to each tube, followed by 3ml of DPIP solution. Immediately wrap 1 tube in aluminum foil and place in a dark refrigerator. Add several crystals of sodium dithionite to the second tube and use it to set 100% transmission in a spectrophotometer. Next, insert the third tube and read the optical density (OD), note the time, and record OD and time. Place this tube in front of a light bulb (about 20cm) and record its OD every 5 minutes for 30 minutes. After 30 minutes read the OD of the tube kept in the dark and the tube to which sodium dithionite was added. Plot OD vs. time for the tube expose that had been exposed to light.

- What does the tube to which sodium dithionite was added represent?
- What does the tube in the dark represent?
- How can the results be explained in terms of the Hill Reaction?
- Explain the role of DPIP in the experiment.

(Source: Dr. J. Carrier, Albion College, Albion, MI, 1980)

References

Apple Computer Co., Inc. 1980. Applesoft Tool-Kit Manual, 33pp.

Bidwell, R.G.S. 1979. Plant Physiology, MacMillan Publishing, Inc., NY, 726pp.

Raven, P.H., R.F. Evert and H. Curtis 1976. Biology of Plants, Worth Publishers, Inc., NY, 685pp.

Stryer, Lubert 1981. Biochemistry, W.H. Freeman & Co., San Francisco, Second Edition, 877pp.

Lehninger, Albert L. 1973. Short Course in Biochemistry, Worth Publishers, Inc., NY, 452pp.

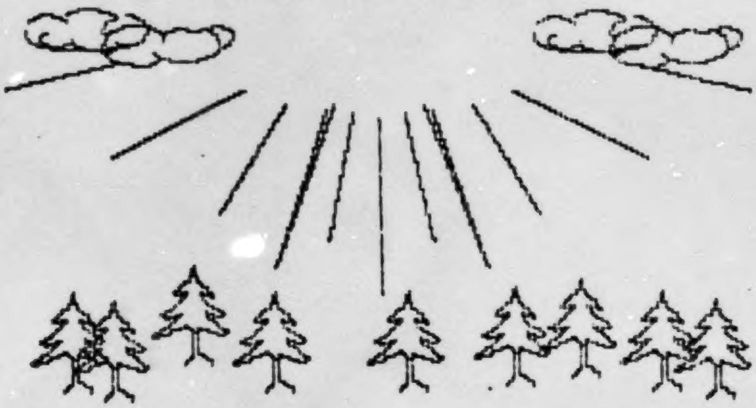
Lehninger, Albert L. 1975. Biochemistry, Worth Publishers, Inc., NY, 1104pp.

Appendix D

Photophosphorylation Written Version

The following is the written material which was presented to the control group in the Photophosphorylation evaluation.

PHOTOPHOSPHORYLATION



Instructions

Read through this module as you would a textbook chapter. When you are instructed to refer to specific pages or figures, you should return to where you left off when you finish examining the reference. Note that terms normally containing superscript and/or subscript notation have been written here without such notation (example: H+).

Introduction

Photosynthesis is the conversion of light energy to chemical energy within a plant. The reactions involved take place in two stages.

Light Reactions

Basically, in the first stage, light energy is used to convert ADP to ATP to provide the plant with usable energy. Also, NADP+ is converted to NADPH to provide the hydrogen and electrons needed to reduce carbon dioxide to carbohydrates. These reactions require light, thus they are called the LIGHT REACTIONS of photosynthesis or PHOTOPHOSPHORYLATION.

Dark Reactions

In the second stage, the energy products of the light reactions are used to convert carbon dioxide to carbohydrates. The reactions of the second stage do not require light, thus they are called the DARK REACTIONS of photosynthesis; they actually take place under light AND dark conditions.

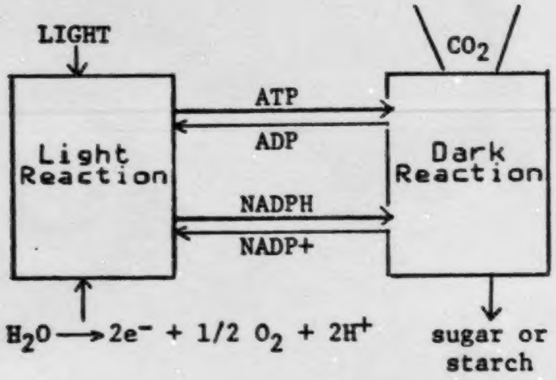


Figure 1. Summary diagram of photosynthesis.

Figure 1 is a diagram of photosynthetic products being formed and used. Keep in mind ... even though products appear to form one at a time in this diagram, these and other reactions occur simultaneously in the plant cell.

Chloroplasts

Photosynthesis takes place in highly specialized organelles, the chloroplasts or chloroplastids. Chloroplasts are found in all higher plants, bryophytes and most algae. Chloroplasts exist in the cytoplasm of photosynthetic cells, such as leaf cells. The dark and light reactions occur in all chloroplasts, but each occur in a different location inside the organelle.

Chlorophyll

The pigment chlorophyll is found in chloroplasts. It exists in many forms which differ in their structure and the wavelength of light they absorb. The leaves of many plants are green because they contain high amounts of chlorophyll relative to other pigments. Chlorophyll absorbs violet, blue and red light and reflects, or transmits, green light.

Pigment Systems

Chlorophyll and other pigments involved in the light reactions of photosynthesis make up two pigment systems. These systems are called Pigment System I and Pigment System II. Their function is to absorb light that strikes the leaf and convert the light to chemical energy.

Let's go on and look at a diagram of photophosphorylation. Don't expect to understand it just yet. This is just to give you a feeling for the pathway as a whole. Then we will break it down into parts to examine what's happening at the molecular level.

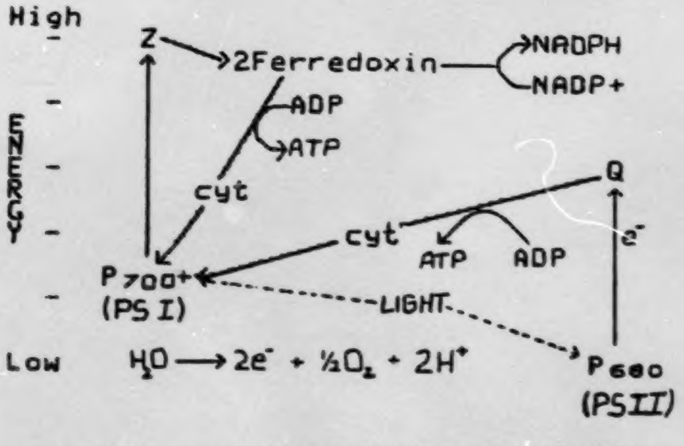


Figure 2. Summary diagram of photophosphorylation

When you are through looking at Figure 2 for now, go on to the next page.

Now that you have seen the whole pathway, let's break it down and examine the parts. We will start by looking at the two pigment systems involved in photophosphorylation, Pigment System I and Pigment System II.

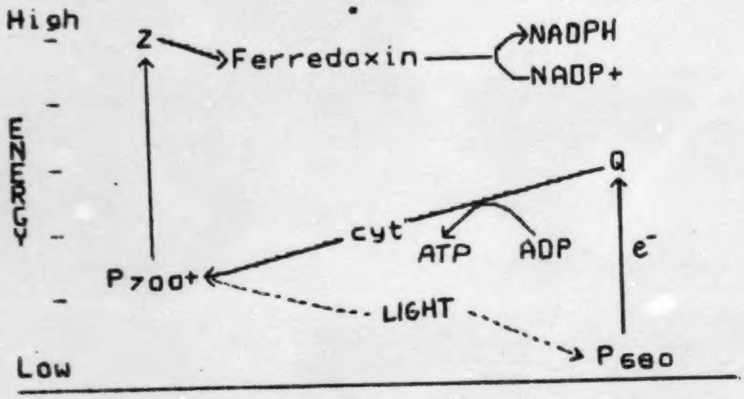


Figure 3. Summary diagram of non-cyclic photophosphorylation

<Throughout the following description, refer to Figure 3>

This diagram (Fig.3) represents part of the photophosphorylation pathway. The components of this pathway were determined through experimentation with chloroplasts.

The reactive chlorophyll molecule in Pigment System I (PS I) is called P700. The reactive chlorophyll molecule in Pigment System II (PS II) is called P680. When the appropriate color of light strikes PS I or PS II, an electron in the reactive molecule (P700 or P680) is raised to an excited state. This means that the reactive molecule is raised above its ground state to a higher energy level. This activates the electron so it may be passed to an acceptor molecule.

As we look at each electron acceptor, keep in mind that a molecule will not accept an electron unless it is already lacking an electron.

When light strikes P680 (PS II), it donates an electron to the acceptor molecule "Q." P680+ then returns to a lower energy level. The + sign indicates that the molecule is missing an electron, thus it is positively charged.

P680 then draws an electron away from a molecule of water. This causes the water molecule to split, thus oxygen is released from the plant. Once P680 accepts the electron it needs, it returns to its ground state and remains at this energy level until it picks up more light waves of the appropriate wavelength.

Meanwhile the excited electron is passed by "Q," a molecule of plastoquinone, to a series of cytochromes and other electron carriers which act as electron acceptors and donors. As the electron is passed it loses some of its energy to each electron carrier. This energy drives the spontaneous "downward movement" of electrons. Even though the electron loses energy as it passes through the cytochrome chain, it is still at a raised energy level, relative to its initial energy level, when it is finally accepted by P700.

As the electron is passed along the series of cytochromes, the energy needed to join ADP and inorganic phosphate is trapped. Thus a molecule of ATP is formed.

If you would like a definition of ATP, briefly turn to page 10.

It is because of this light activated phosphorylation of ADP to form ATP, that the light reactions of photosynthesis were named "photo - phosphorylation."

Remember that ATP and ADP molecules move to and from the pathway. The dark reactions, which occur elsewhere in the chloroplast, use ATP and produce ADP.

What causes P700 to be boosted to a higher energy level?
<Briefly turn to page 10 (F) to check your answer>

What must be missing from a P700 molecule, at the molecular level, before it can accept an electron from a cytochrome molecule?
<Briefly turn to page 10 (A) to check your answer>

When light strikes PS I, P700 donates its electron to acceptor molecule "Z." It then returns to a lower energy level, but does not return to its ground state until it accepts another electron. The molecule Z passes the electron down an energy gradient to ferredoxin, an iron protein. If there is sufficient NADP+ to accept the electrons from ferredoxin, then ferredoxin donates its electrons to NADP+. For every two electrons donated, one molecule of NADPH is formed.

If you would like a definition of NADP, briefly turn to page 10.

From what molecule involved in this pathway do you think the second electron comes?
<Briefly turn to page 10 (E) to check your answer>

Since ferredoxin is only a one-electron carrier, two molecules of it are needed, one for each electron. These electrons then converge to form one molecule of NADPH from NADP+.

A hydrogen ion is also needed to form NADPH from NADP+. Of the molecules we have discussed so far, which do you think supplies the hydrogen ion?
<Briefly turn to page 10 (C) to check your answer>

After a molecule of NADPH forms, it "moves from the pathway" to be used in the dark reactions elsewhere in the chloroplast. The dark reactions produce the NADP+ which gets used in the light reactions. When two molecules of ferredoxin again have one electron each to donate, they will pass them to NADP+ if it is available.

The pathway that we just traced through (Fig.3), ending with the formation of NADPH, is called NON-CYCLIC photophosphorylation. It is called "non-cyclic" because electrons essentially flow from water to NADP+ without cycling back to P700.

At this point you may:

1) review this section on non-cyclic photophosphorylation p.3

2) go on and learn about cyclic photophosphorylation p.6

Turn to the page number which corresponds with your choice.

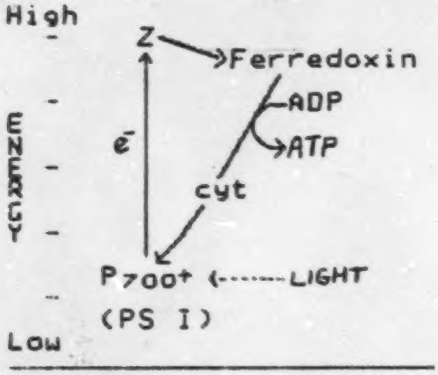


Figure 4. Summary of cyclic photophosphorylation.

<Throughout the following description refer to Figure 4.>

This pathway (Fig.4) represents what biologists believe to be CYCLIC photophosphorylation. Notice that it contains portions of the non-cyclic pathway (from Fig.3). Biologists believe the plant utilizes this pathway when NADP+ is not available to accept electrons from ferredoxin.

NADP+ is not shown in Figure 4 because we would like to discuss what happens when it is not available to the photophosphorylation reactions.

Let's assume that an electron has been boosted to a higher energy level by light, and passed from water to ferredoxin via non-cyclic photophosphorylation. This means that ferredoxin needs to donate the excited electron to an acceptor so it can become a stable molecule.

When NADP+ is unavailable, the electron is donated to a chain of various cytochrome molecules. As in the non-cyclic pathway, the electron loses some of its energy to each cytochrome, and some of its energy is trapped to form a molecule of ATP. The formation of ATP in the cyclic pathway keeps ATP supplied to the cell in the absence of non-cyclic photophosphorylation. If there is a surplus of ATP it can be used for other synthetic processer, in addition to the dark reactions.

Unlike the formation of NADPH, only one molecule of ferredoxin is needed to donate an electron back through the cytochrome chain to P700. Because we are assuming P700 donated its electron to ferredoxin it follows that it has a need for an electron. Therefore it accepts the one passed "down" through the cytochrome chain.

Once P700 has accepted this electron, is it in its ground state? <Briefly turn to page 10 (B) to check your answer>

Is PS II (P680) involved in cyclic photophosphorylation? <Briefly turn to page 10 (D) to check your answer>

As long as 1) NADP+ molecules are unavailable and 2) light of the appropriate wavelength is present, the excited electron will continue to cycle.

This ends the explanation of cyclic photophosphorylation. Next you will be presented with 5 questions. Each question may deal with the cyclic pathway, non-cyclic pathway, or both. When you are through examining Figure 4, turn the page for the first question.

You may skip the upcoming questions if you have already answered them once (i.e. if this will be a review for you).

1) cyclic 2) non-cyclic 3) both 1 & 2

Respond to each question by entering the number 1, 2 or 3, depending on which choice correctly answers each question below. Decide on your answer for each question and turn to the appropriate page to check your answer and receive an explanation.

- Which pathway produces net ATP?
  <see page 11 (H)>
- Which pathway involves PS II?
  <see page 10 (G)>
- Which pathway produces oxygen?
  <see page 11 (K)>
- Which pathway takes place only in the light?
  <see page 11 (J)>
- P700 is the reactive chlorophyll molecule of which pathway?
  <see page 11 (I)>

Keep these questions in mind when you review the diagram of the entire photophosphorylation pathway (Fig.1) after reading the summary on the next page.

The outstanding features of cyclic and non-cyclic photophosphorylation are summarized below:

NON-CYCLIC
  1) involves PS I and PS II
  2) produces ATP and NADPH
  3) causes water to split and release oxygen

CYCLIC
  1) involves PS I only
  2) produces ATP, but not NADPH
  3) does not involve water, therefore oxygen is not produced

Well, that sums up photophosphorylation. At this point you should review Figure 2, the summary diagram of the entire photophosphorylation pathway. Hopefully it will make more sense this time. You should also review Figure 1, the summary diagram of photosynthesis. Reviewing these two diagrams should help you pull together all of the information presented in this module. Also, be sure to review any section you do not understand.

Remember, many of the reactions in the above pathways, occur simultaneously in the chloroplasts of each photosynthetic plant cell.

Appendix A

Definition of ATP:
ATP functions as the major carrier of chemical energy in the cells of all living organisms. As it transfers energy to other molecules it loses its terminal phosphate group and becomes ADP. ADP can accept chemical energy by gaining a phosphate group, thus it becomes ATP. In the case of plants, ATP forms at the expense of solar energy.

Definition of NADP:
NADP is an organic molecule that carries electrons from electron donors to electron acceptors. In this case, NADP accepts electrons from ferredoxin and carries them to the part of the chloroplast where the dark reactions occur. The electrons are then donated to available electron acceptors in the dark reactions.

(A) The answer is electron. A molecule cannot accept an electron unless it is first missing an electron.

(B) The answer is yes. Once P700 accepts the electron which was passed through the cytochrome chain, it has fulfilled its need for an electron. Thus it returns to its ground state energy level.

(C) The answer is water. There may be other sources of hydrogen ions in the chloroplast, but water splits and donates the hydrogens to NADP+ when light is present.

(D) The answer is no. The electron which fills the "electron hole" in P700 (PS I) is constantly recycled, thus the reactive molecule in PS II (P680) is not needed to donate an electron. P680 will still be activated when light strikes PS II, but it will not be able to pass its excited electron very far along the non-cyclic pathway when the plant is utilizing the cyclic pathway.

(E) The best answer is water. The second electron comes from P680, which originally accepted it from water. It follows the same pathway that the first electron did because a molecule of NADP+ is available to accept it.

(F) The answer is light (energy). The color of light appropriate for PS I strikes a reactive molecule of P700. Thus an electron is excited, causing P700 to be raised to a higher energy level. If the light source is turned off, the entire pathway "shuts down" at the reactive chlorophyll molecules. That is, no electrons can be passed from these molecules in the dark.

(G) The answer is 2 (non-cyclic). The non-cyclic pathway is the one which involves PS II as well as PS I. The cyclic pathway only involves PS I.

(H) The answer is 3 (both cyclic and non-cyclic). Both the cyclic and non-cyclic pathways produce ATP. This results in a net gain of ATP which can be used in the dark reactions of photosynthesis or in other synthetic pathways when in surplus.

(I) The answer is 3 (both cyclic and non-cyclic). P700 is the reactive molecule in PS I, and PS I is involved in both pathways. Also, do not forget that the reactive molecule in each pigment system does not make up the entire pigment system. There are other pigments involved also.

(J) The answer is 3 (both cyclic and non-cyclic). The entire process of photophosphorylation requires light. Therefore both pathways require light. Remember how the pathway got its name.

(K) The answer is 2 (non-cyclic). Since the non-cyclic pathway is the one which involves water, it is the one that produces oxygen when a water molecule splits.

Appendix E

Photophosphorylation Study Guide

The study guide is a copy of the instructions and objectives given to all students participating in the Photophosphorylation evaluation. Occurring in parentheses after each objective, for the purposes of this report, are the item numbers of the items on the Photophosphorylation Test which fit each of the objectives.

Today you will look at a module entitled Photophosphorylation. You will either run the computer program version or read a written version as specified by your instructor. The written version is a printed copy of the text and diagrams presented in the computer program.

Below is a list of learning objectives (things you should learn from the module). These are listed in the order in which they occur in the module to help guide you. You will take a written 20 question multiple choice quiz immediately after you look at the module. The quiz questions are all taken from (based on) the below objectives. IF YOU MEET THE BELOW OBJECTIVES WHILE USING THE MODULE, YOU WILL DO WELL ON THE POST-QUIZ.

IMPORTANT: This quiz score may replace your lowest quiz grade in recitation! There will be one question pertaining to this module on your recitation quiz next week. There will also be questions about photophosphorylation on your final exam in lecture.

Objectives:

-Comprehend why the light reactions of photosynthesis require light and the dark reactions of photosynthesis do not. (5,8)
-Identify the products supplied to the dark reactions of photosynthesis by the light reactions of photosynthesis and vice versa. (1,17)
-Recall where, in the cell, the light and dark reactions of photosynthesis occur. (18)
-Explain why Pigment System I and Pigment System II are activated by different wavelengths of light. (2)
-Distinguish between an electron acceptor and an electron donor. (3)
-Explain the relationship between ground state energy level of a molecule and its excited energy state. (9)
-Explain how light is related to the release of oxygen from a plant. (6)
-Identify the contributions made by water to photosynthesis. (12,14)
-Recognize what conditions and/or molecular components are necessary for a molecule of ATP or NADPH to form during photophosphorylation. (7,20)
-Recall the conditions necessary for cyclic photophosphorylation to occur. (8,15,16)
-Predict where an electron will go in the photophosphorylation pathway, given its location in the pathway. (10,19)
-Distinguish between cyclic and non-cyclic photophosphorylation based on the components and outputs of each. (4,10,11,13)

Appendix F

Photophosphorylation Quiz

The following is the test administered to students immediately after they completed the Photophosphorylation module, as part of its evaluation. Correct answers are indicated with an asterisk for the purposes of this report.

RECORD YOUR NAME AND STUDENT NUMBER ON THE COMPUTER ANSWER SHEET. Choose the most appropriate answer for each question and mark it on the answer sheet. Note that terms normally containing subscript and/or superscript notation have been written without such notation (examples: P680, NADP+). PLEASE DO NOT WRITE ON THIS QUIZ.

1. Which of the following are produced by the light reactions of photosynthesis (photophosphorylation) and used in the dark reactions of photosynthesis?

*A. ATP and NADPH
B. ADP and NADP+
C. ATP and NADP+
D. ADP and NADPH

2. Pigment System I (PS I) and Pigment System II (PS II) are activated by different wavelengths of light because they have different

A. cytochrome molecules.
*B. pigment molecules.
C. locations in the chloroplast.
D. ground state energy levels.

3. Which of the following is in the proper molecular condition to accept an electron?

*A. P680+
B. NADPH
C. OH-
D. P700
E. more than one of the above is correct

4. Which of the following is true of cyclic photophosphorylation?

A. involves PS II (P680) only
B. ATP is not produced
*C. oxygen is not produced
D. all of the above are true

5. The light reactions occur only when the plant is exposed to light.

*A. true
B. false

6. Oxygen is produced when

*A. P680 removes an electron from water.
B. P680 donates an electron to water.
C. NADP+ removes an electron from water.
D. NADP+ removes a H+ from water.

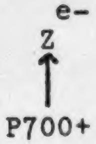
7. Which of the following is needed to form a molecule of NADPH from NADP+?

*A. 2 electrons, 1 H+
B. 1 electrons, 1 H+
C. 1 electrons, 2 H+
D. 2 electrons, 2 H+

8. When cyclic photophosphorylation is in use, it keeps cycling the same electron through the pathway. Therefore the cyclic pathway does NOT require light to function.

A. true
*B. false
C. sometimes true, sometimes false

9. Based on this portion of the photophosphorylation pathway, which of the following best describes the condition of P700?



A. ground state energy level
B. excited energy state
*C. between excited and ground states
D. none of the above

10. Which of the following best describes what happens as an electron is passed through a cytochrome chain in photophosphorylation?

A. energy is lost by the electron
B. energy is trapped to form ATP
C. P700 returns to its ground state
D. none of the above, it depends on which cytochrome chain one is referring to
*E. A, B, and C

11. Which of the following is associated with the cyclic pathway of photophosphorylation?

- A. Q (plastoquinone)
- B. P680
- C. NADP+
- D. H+
- *E. ADP

12. Which of the following is DIRECTLY related to water in the photophosphorylation pathway?

- A. ferredoxin
- B. P700
- *C. NADP+
- D. none of the above

13. Assume that plant cells were treated with a chemical known to inhibit transfer of electrons by cytochromes. What would you expect to occur?

- A. only the cyclic pathway of photophosphorylation would be inhibited
- B. only the non-cyclic pathway would be inhibited
- C. neither cyclic or non-cyclic would be inhibited
- *D. both cyclic and non-cyclic would be inhibited

14. Based on the equation given in the module, how many electrons (total) can one molecule of water contribute to photophosphorylation?

- A. 1
- *B. 2
- C. 3
- D. 4

15. Where do electrons, obtained from water, end up during the process of non-cyclic photophosphorylation?

- A. oxygen
- *B. NADPH
- C. ATP
- D. P700

16. Where do the electrons of ferredoxin go when NADP+ is NOT available to serve as an acceptor?

A. they remain attached to ferredoxin
B. they combine with H+ ions
C. they combine with ATP to make ADP
*D. they return through the cytochromes to P700

17. Which of the following is NOT produced by the light reactions of photosynthesis?

A. ATP
B. NADPH
C. oxygen
*D. sugar

18. Which of the following occurs in the chloroplasts of plants?

A. light reactions of photosynthesis
B. dark reactions of photosynthesis
*C. both light and dark reactions
D. neither, both photosynthetic pathways occur outside the chloroplast

19. Which of the following correctly describes the sequence followed by electrons which leave P680 (PS II)?

A. cytochromes, Q (plastoquinone), P700
B. P700, Q, cytochromes
C. cytochromes, P700, Q
*D. Q, cytochromes, P700

20. How many times does a molecule of P680 (PS II) need to be activated by light to produce one molecule of NADPH?

A. 0 (P680 is not involved in producing NADPH)
B. 1 time
*C. 2 times
D. 4 times

Appendix G

Photophosphorylation Lecture

The following is the lecture presented by the BL 104 instructor 42 days prior to the Photophosphorylation evaluation. This provides an idea of student background, for those students participating in the evaluation.

Plants have many of the same energy needs as animals (synthesis of proteins, nucleic acids, cellulose, etc.). However they have the advantage of being able to to produce ATP energy from light by the process of photophosphorylation. This process occurs in plants in the chloroplast; an organelle which contains chlorophyll molecules arrayed on a membrane in clusters in order to perform two kinds of photophosphorylation. In each case the chlorophyll is important in that:

A. It can absorb light with the consequence that one electron in the molecule is activated to a higher energy level.

B. Unlike most molecules this activated electron can be forced into some acceptor molecule and thereby causes it to be reduced (reverse of being oxidized). This reduced acceptor can then react in either of two ways:

1. To produce the reduced coenzyme NADPH2 (Nicotinamide Adenine Dinucleotide Phosphate, a coenzyme similar to NAD).
2. To pass its electron through a chain of reactions similar to the respiratory cytochrome electron transport chain with the consequent production of ATP.

Both of these results occur in the process called non-cyclic photophosphorylation.

C. Non-cyclic photophosphorylation - in this process electrons are taken from water (with the result that oxygen is formed), passed to the chlorophyll molecules, activated twice by light to a high energy level, and after several transfers finally end up being used to reduce NADP to become NADH2. This process is called non-cyclic because electrons start at water, and end up in the NADPH2 molecule. Note that the end result is almost the opposite from that which happens in the respiratory cytochrome electron transport. In respiration, we start with the reduced coenzyme NADPH2, and electrons and hydrogens are passed down the energy gradient to oxygen to form water; energy was produced as ATP. In non-cyclic photophosphorylation hydrogens and electrons are removed from the oxygen of water and pumped up the energy gradient by light to produce the reduced coenzyme NADPH2.

D. Cyclic photophosphorylation is believed to be a relatively minor process which results in chlorophyll electrons being pumped up to a high level by light, passing back through a chain of cytochrome to chlorophyll again yielding ATP as a product. The electrons cycle around, no oxygen is formed, no NADPH2 is formed, only ATP.

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Appendix H

BL 104 Class Statistics

Following are the field of study, sex and academic year statistics summarized for individuals in each treatment group of the Photophosphorylation evaluation. Also indicated are the number of people who attended each lab section for the evaluation. The lab sections were at the following times:

Section	1	Thursday	(1/21/82)	12pm - 3pm
	2	Thursday		3pm - 6pm
	3	Thursday		7pm - 10pm
	4	Friday	(1/22/82)	9am - 12pm
	5	Friday		12pm - 3pm

	Groups			
	CM	CL	WM	WL
Field				
Bio. Sci.	1	1	2	1
Forestry	10	8	11	11
Computer Sci.	3	1	2	1
Engineering	5	9	5	10
Other	6	7*	5	3*
Academic Year				
Freshman	18	16	18	17
Sophomore	6	4*	3	3
Junior	1	4	2	3
Senior		2	1	3
Post Graduate			1	
Sex				
Male	16	17*	16	20*
Female	9	9	9	6
Lab Section				
1	4	6	5	4
2	5	5	4	6
3	4	5*	6	6*
4	6	5	4	5
5	6	5	6	5

CM = computer/module first
CL = computer/lab work first
WM = written version/module first
WL = written version/lab work first

*Subtract 1 when considering ANOVA and related statistics, to account for two students being randomly eliminated.

Appendix I

Schedule of Lab Topics and SUMIT Programs Used in BL 104

The following schedule outlines the topics covered and the SUMMIT programs available during the first six weeks of BL 104, winter quarter (beginning 11/30/81). CAI programs were assigned as either manditory or optional each week.

Lesson (week)	Topic	SUMIT CAI programs	Lab Sections				
			1	2	3	4	5
1	Cell structure	Cell Structure	M	O	O	M	O
2	Chemistry	Enzyme Activity	O	M	O	O	M
3	Genetics	Mitosis/Meiosis	M	O	O	M	O
	- - -	Two Week Vacation	- - -				
4	Genetics 2	Monohybrid Cross	O	M	O	O	M
5	Animal Behavior	Life Expectancy & Baffles (games)	O	O	O	O	O
6	Ecology/Soil	Photophos.	M	M	M	M	M

M = Manditory
O = Optional